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MULTI-ECHELON INVENTORY

IMPACT OF VARIED ORDERING POLICIES ON REALIZED SERVICE LEVELS

A Thesis in

Business Administration

by

Stephan P. Brady

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

August 1999

We approve the thesis of Stephan P. Brady.

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ABSTRACT

Wholesalers face an environment where different retail establishments may follow different ordering policies. Typically, wholesalers do not consider the individual retail establishment's ordering policies when setting and computing their service levels. This research looked at whether there was a negative impact on retailers due to interactions between ordering policies.

Current research has focused on serial relationships in multi-echelon inventory problems. This research extends existing research by assessing the impacts of differing ordering policies upon service level performance for each retail level establishment in a parallel multi-echelon inventory environment, for slow-demand items.

Conducted through the use of simulation, one model was developed representing three ordering policies: Periodic Review, Continuous Review, and an Instantaneous Reorder Policy. Each policy was isolated, and the models run to get a baseline of performance. Finally, the complete model was run, and comparisons were made between the performance of the policies alone, and interacting. Runs were conducted over a range of customer demand rates and target service levels. Lead times and customer demand rates were exponentially distributed. Of interest is whether the achieved service level at least meets the target service level for the individual run.

This research focused on four research questions. This research concluded that the three reordering policies generally performed as well as, or better, than the theoretical target service levels, both for when they were run independently, and for when the

policies were allowed to interact. There was generally no statistical difference between the performance of identical policies when isolated and when run concurrently. Additionally, it was found that there exists a statistical difference between the policies when interacting. Typically, the periodic review policy's achieved service levels was lower in comparison to the other two policies under conditions of slow demand, and was higher than the other policies as demand approached one per day.

While some policies outperform others, each policy meets or exceeds the target service level, suggesting that other considerations may be more appropriate to decision makers. This research concludes that inventory reordering decisions should continue to be made using economic and other factors.

Further research should look at other ranges and distributions of demand, as well as lead-time. Additionally, other influences on the supply chain may be integrated into the model. Finally, analysis of the cycle stock for each ordering policy may be of greater value in assessing costs reductions available through alternative ordering policies.

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ACKNOWLEDGMENTS

My wife, Jennifer, has been with me through many trying times in my military career, and supporting me through this process has to be one of her greatest challenges. She has always had, and continues to have, my heartfelt thanks and undying love. Also, our three children are a tremendous inspiration, and have been understanding of those times when they have had to "endure" and allow Dad time to study. I hope I am able to repay them for the wonderful support they have provided me.

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CHAPTER 1

INTRODUCTION

Background

The Defense Logistics Agency (DLA) has established a threshold customer service level (identified as P_2, or percentage of total units demanded satisfied from stock) and has had overall moderate success at meeting that service level for all customers (the military branches.) After discussing their stock-out performance with representatives from each of the branches, they find that for like items the individual branches are receiving deliveries at varying satisfaction rates, depending upon the branch of the military service. That is, for example, while the DLA has a customer service (or fill) rate of nearly 95% for all their customers, individual customer groups find their own experiences to be somewhat different. For instance, the Army's orders for part type 1 are satisfied 97% of the time; while the Air Force may find that only 75% of their orders are satisfied for the same item.

Further review of the problem reveals that each of the branches follows different ordering policies, and each has established different rules for setting their inventory range, depth, and reorder points for DLA-managed expendable spare parts. For instance, the Army often follows a simple periodic review rule maintaining "days of supply" while

the Air Force follows an EOQ/continuous review policy. Typically, each of these policies is established with specified target service and safety stock levels.

The military can be seen to mirror the commercial sector in structure. The individual operating locations (bases, forts, and posts) are the equivalent of individual retail establishments. The DLA facilities are the equivalent of a wholesale point. Given this, the problem faced by DLA can conceivably be faced by any commercial wholesaler.

This research seeks to determine the relative impact upon service level performance for each retail level establishment, and whether certain retail level ordering rules result in better performance than others, given a single second echelon service point. This can be modeled as a representation of the various interactions of the demand/lead time policies and quantities. This research focuses on the impacts of various inventory policies when demand distributions are identical across retail establishments. Sensitivity analysis is conducted to assess any variation in service as demand frequency and/or lead-time change.

Operational Setting

Figure 1-1 reflects the general flow of demands and supply through the DLA system. "Benchstock" represents the items located with the technicians and mechanics as part of their daily operating stock. The benchstock inventory levels are established by inventory control specialists. When the technicians or mechanics ("customers" in a traditional retail establishment) drop below their daily stock levels, they then go to the base or post supply point. This supply point is the "retail group." This is the central

point that is responsible for stocking and requisitioning for the installation and is the equivalent of a local retail establishment. As the "customers" place demands on the retail groups, these groups then meet the demands from their existing stock, if available, and place orders to the depot based on reorder policies. "Depot," in the instances we are studying, refers to the DLA warehouses/supply points. The depot then fills demands from existing stock, when available, and follows their reordering policy in placing demands on their supplier. "Supplier" is reflected here as a single source, however it is known that there may be multiple sources of supply for a given stock number or for “suitable substitutes.” The inventory review/order policies listed reflect three existing policies followed by different retail level organizations.

Multi-Echelon Inventory

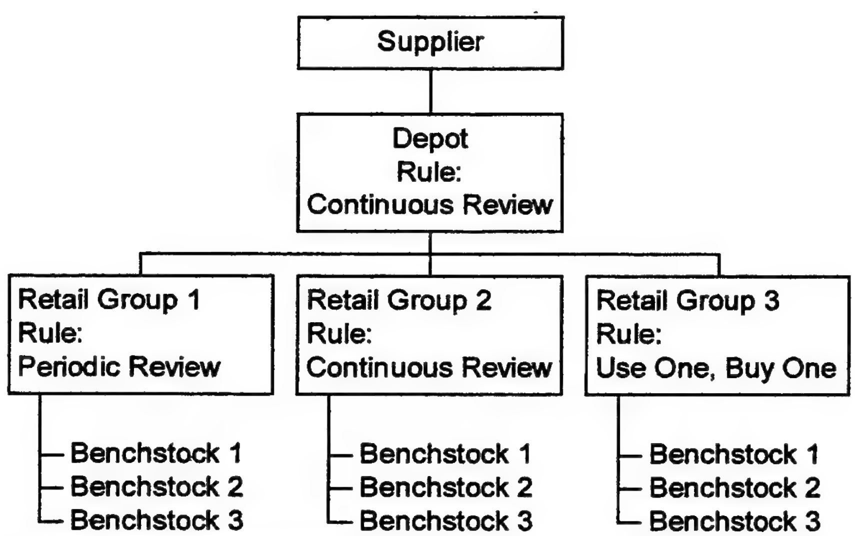

Figure 1-1 - Scope of Research

Contribution

This work contributes to the theoretical literature in multi-echelon inventory analysis by opening the discussion to parallel multi-echelon systems versus serial systems, and considering systems with differing ordering policies at the retail level. Current literature focuses solely on serial systems and thus this research explores the instances when the systems cannot be assumed to be serial given the constraint of differing ordering policies. This work expands on past research through the evaluation of the impacts and interactions of varied inventory policies, concurrently executed by parallel retail establishments, on realized customer service levels at the retail level.

In practice, this work can directly relate to decisions made in DLA and other defense and civilian organizations facing differing ordering policies in place at retail level operations. DLA has made it clear that they want to understand the inter-relationships of various ordering rules and the impact of the relationships on their ability to meet customer demands. This research can provide them an understanding of that relationship, and therefore can guide DOD-wide inventory ordering policies, or allow for increased flexibility in DLA ordering policies. This work also has potential implications in the commercial sector for wholesalers and suppliers who work with retailers when those retailers follow varied ordering policies.

This research studies the impact of differing ordering policies between retail establishments, and the possible effects on service levels that may result from the interactions of these differing ordering policies through the supply chain. Simulation will

be used to model the supply chain, and sensitivity analysis will be conducted through modifying the variables of interest.

Research Questions

In pursuing this research, four research questions were formed on which to frame the analysis.

1. Does a difference exist between expected and realized customer service levels for the individual retail establishments? This question can be considered regardless of whether each retail establishment has chosen identical customer service targets or not. This question is treated in two parts.

   1A. First, given the parameters and assumptions used, does each individual policy meet the theoretically expected values, and;

   1B. Second, when the fully integrated, and interactive model is run, does the performance of each ordering policy meet the theoretically expected values?

2. If a difference exists between the theoretical expected value and that actually achieved, does a difference then exist between the performance of a given policy when no competing policies exist and when the fully interactive model is used?

3. Do varied ordering policies at the retail level result in differing service levels between the retail establishments? This question is applicable when the retail

establishments have each established their safety stock and ordering quantities based on identical service level goals.

4. If a difference exists between expected and realized customer service levels, does one retail level ordering/review policy tend to outperform other policies? This question takes this process from a purely descriptive research effort and begins to look at the prescriptive aspects.

Study Approach and Organization

Supply chain relationships are generally complex, and this relationship is made more complex when policy differences exist between the various retail organizations. This paper uses discrete-event stochastic simulation modeling to evaluate the potential service level outcomes resulting from the interactions. Through simulation the impact of the interactions between lead time, demand, and ordering policies can be measured.

Chapter One has provided an overview of the research and discussed the contribution to the body of multi-echelon inventory theory. This chapter also identified the research questions under consideration.

Chapter Two reviews the extant literature in two areas. First the literature related to multi-echelon inventory theory is reviewed. Second, the current literature on the basic inventory theoretic model is discussed, and specifically as it relates to the calculations necessary for computing the safety stock levels required in this research. Palm's Theorem will be presented as part of the discussion of inventory and safety stock determination as it relates to instantaneous reorder policies. Simulation as a tool is briefly discussed, along

with a review of literature concerning verification and validation. Finally, the research problem is related to the current literature.

Chapter Three discusses the methodology followed in this research. This chapter discusses the decision to use simulation and the sensitivity analysis approach being used. Additionally, the rationale is presented for using the exponential distribution for both lead-time and demand. The commonly accepted algorithms used to compute safety stock and reordering points are also presented, including the Visual Basic for Applications coding. In addition, the algorithms/heuristics used in the model for computing safety stock and the reorder points for the various reordering policies are considered. This chapter also familiarizes the reader with the simulation and analysis tools being used. Finally Chapter Three presents a synopsis of the assumptions in this model and the limitations imposed on the research by this approach.

Chapter Four provides analysis and findings for the research. In this chapter the research questions are presented as testable hypotheses. The results of the simulation are tested against each of the hypotheses. The data analysis is then presented.

Chapter Five lists the conclusions drawn, recommendations, and directions for further research.

Chapter 2

LITERATURE REVIEW

This chapter reviews the extant literature in three areas. First, the literature related to multi-echelon inventory theory is reviewed. Second, the current literature on the basic inventory theoretic model is discussed, specifically as it relates to the calculations necessary for computing the safety stock levels required in this research. Third, a brief overview is provided of the current simulation modeling literature as a foundation for pursuing this form of analysis. Subsequent to this, a discussion is presented concerning the role of verification and validation in the conduct of research using simulation modeling techniques. Finally, the literature is related to the research problem under consideration.

Multi-echelon Inventory Research

Models of multi-echelon inventory and distribution systems follow a general format, dictated quite obviously by the actual flow of orders and inventory. Jay Forrester, in his work Industrial Dynamics (1968), identified "levels and rates" as being the two major areas of variables. All analysis is therefore a study of the interactions of these variables. In addition, he argues that most of the variables are common to each of the three functions in the multi-echelon model; the retailer, warehouse, and supplier.

Levels identified by Forrester include inventories, backlogs of orders, and past demand history for forecasting. He also identified the rates of interest as: incoming order (demand) rate, shipping/delivery rate, outgoing rate for orders to the next function, and the delivery rate from that function. Of course, other rates and levels may be added to account for variations in specific systems (Forrester, 1968).

It can be seen that this generally defines any inventory and distribution system. In fact, it is a proper framework for understanding the interactions of levels and rates. One other type of variable that could be included is delays, including delays in filling orders, in shipping, and in administrative issues. These generally are contained (or embedded) in the "rates" variables, but could be explicitly delineated if these are areas of interest (Forrester, 1968).

A great deal of literature is available concerning multi-echelon inventory problems. Most of the literature approaches the problem from a prescriptive perspective, seeking to find the optimal review/ordering policies for use in such situations. In his retrospective of the multi-echelon problem, Andrew Clark states that "The most usual policy is to minimize the overall costs of carrying inventories in the system as a whole..." (Clark, 1994). DeBodt and Graves, in their article, state that their "objective is to find a continuous-review inventory policy that minimizes the expected average costs." (DeBodt. 1985).

One interesting approach in literature is the echelon stocking policy, first proposed by Clark and Scarf. In this approach, the warehouse ordering decisions are based on the total inventory in the system, including the warehouse, all it's retail outlets,

and the inventory in transit (Clark and Scarf, 1960). In their model retail service level decision processes remain the same, but warehouse decisions are based on total inventory visibility for the warehouse, the retailers and inventory in transit between the two. This contrasts with the standard stocking policies where each retail location and the warehouse determine their policies based on their own stocking levels. Clark and Scarf show in their article that their approach is optimal when considering a serial system. They point out that their approach "departs from optimality" when it is applied to "several installations with the same supplier" (Clark and Scarf, 1960). Given this, the approach may not be optimal for the model under analysis but may bear further review.

Axsäter and Juntti looked further at the echelon versus installation stock policies, and sought to define the worst case situations for costs between the two policies. While they found this to be done simply for a serial system, they conclude that generalizing "to a distribution system with several retailers seems much more difficult." They point out that one could apply, as a simplifying assumption, that all retailers' order simultaneously. Of course, this would allow the problem to appear "more or less identical to a serial system" (Axsäter and Juntti, 1996).

Axsäter and Juntti conducted a simulation study of echelon stock versus installation stock policies for "distribution systems and stochastic demand." In their model, they assume identical ordering policies and quantities, and identical Poisson distribution demands at each of up to 10 retail outlets. Given these simplifying assumptions, they conclude "that echelon stock policies dominate... when the warehouse lead-time is short." They also show that echelon policies gain the advantage as the

warehouse lead-time (the time required to replenish the warehouse) lengthens in comparison to the lead-time for retailer replenishment. They conclude that "when the warehouse lead-time is long, the reorder point should cover several orders from the retailers and the echelon stock illustrates these requirements quite well."

The bullwhip effect is described by Drezner, Ryan, et.al, as an increase in the variability of demand as demand progresses up the supply chain (Drezner, et.al., 1996). In their review of extant literature, they identify "four main causes of the bullwhip effect." These were identified as demand forecasting, supply shortages and nonzero lead times, batch ordering, and price variations.

Much has been written to account for variability as one aggregates demand. The general consensus has been that centralized processes (demand forecasting, and centralized inventory control) could moderate the fluctuations (Lee, Billington, 1993). This approach was questioned by Drezner, et. al., and while they conclude centralization does dampen the effect, they also conclude that the impact is not significant.

Another interesting approach in the literature is to treat both inventory and production systems in a similar manner by defining the production process as a "replenishment" of stock items (Lee, Billington, 1993). This allows for a much broader approach to understanding the process. By defining both production and inventory in this way one can perhaps consider tools for either to assess their applicability for both. In addition this perspective simplifies any modeling efforts by accounting for time in production as additional "lead-time." What is not discussed is viewing inventory systems

as production systems however, the benefits of the broadened view may also apply here as well.

Inventory Theoretic Modeling and Safety Stock Computations

This research considers the interactions of the supply chain in a stochastic environment and thus must consider reordering policies that rely on determining both the timing and the size of an order. In computing this the various organizations rely on safety stock computations to seek assurance of maintaining a given level of service. Standard practice is to consider the convolution of the lead-time and demand (LTD) distributions (X) as following a Normal distribution. Therefore most if not all texts present computing the safety stock as a function of the mean and standard deviation of the LTD.

Some question exists as to whether this is a suitable assumption for computing service levels.(Mentzer, et.al., 1985) In discussing the selection of the Normal distribution Eppen writes, "(un)fortunately the normality assumption is unwarranted in general and this procedure can produce a probability of stocking out that is egregiously in error." (Eppen, et.al., 1988.) Clearly the opinion exists that assuming normality is incorrect. Further research has shown that the assumption of normality is not necessarily a valid assumption, and that using the normal distribution can lead to an over or underestimation of safety stock. This results in realized service levels that differ from the desired service levels. Despite this strong and often supported assertion the assumption

of normality is still the rule rather than the exception, and is chosen "both out of convenience as well as necessity." (Tyworth, 1992) Lau notes the paradox facing the practitioner when he states, "(t)o 'declare' the distributions of d_t, T and/or L as Normal... is convenient but not necessarily accurate, while attempts to obtain their exact probability density functions are impractical" (Lau, 1989, p. 89).

There has been an ongoing discussion in the literature over the past thirty years concerning the validity of assuming normality of the convolution of the lead time and demand distributions (X). As Tyworth has noted, there is division on this point. Two camps have emerged. We have seen above that the first camp asserts that the distribution of X is important and "the wrong density function can cause serious errors in the estimates of reorder points, stockout risks, and lost sales, and thus the inventory system (holding, ordering or setup, and shortage) costs." (Tyworth, et.al., 1997, p. 245) Based on this premise much work has been done to develop computationally tractable means of determining the proper shape of the distribution of X. Such efforts include efforts at developing actual discrete historical data, Markov analysis, simulation, and determining and using the appropriate theoretical distribution. (Bagchi, et. al., 1986, p. 171)

The second camp posits that the "shape of the distribution is not important in many cases for theoretical and practical reasons." (Tyworth, et. al., 1997) While the assumption of normality can lead to large errors, these errors have a minimal impact on the overall ordering policy decisions given the relatively "small portion of the total logistics system cost" associated with safety stock. Additionally, the errors induced are minimized as the mean and variation of lead time is reduced. (Tyworth, 1997)

Most of the research reviewed has centered around analyses of continuous review (s, Q) service level policies, with additional attention paid to periodic review (R,S) service level policies. To satisfactorily conduct this particular research project it is necessary to also review literature concerning the special case of continuous review ordering policies where Q=1, that is, a "one for one" policy. (Sherbrooke, 1992:24) This is represented in literature as both a special case of (s,Q) where Q=1, and also as a special case of the (s,S) policy, reflected as (s-1, S). Much of the work on this type of policy has focused on establishing policies where cost is the concern (B^i policies) (Silver, et.al,, 1998:320), directly applicable for slow moving high cost items. Alternatively, the (s-1,S) policies are discussed when the focus is on reparable pipelines rather than consumable supply lines. (Silver, et.al., 1998:505; Sherbrook, 1992:24; Sherbrook, 1965:2.) As an extension, this policy is appropriate not only when the cost of the item is high, but when other logistics costs are high as well, including storage and transportation.

The National Aeronautic and Space Administration (NASA) saw such an approach as necessary when facing the challenges of the space station program. During interviews conducted as the foundation for unrelated research, it was discovered that the space station program (then "Space Station Freedom") had as it's focus the use of (s-1,S) policies due to both the high cost of the end items, but also the high costs associated with the other "logistics" functions of storage space, and transportation. (Kinney, 1991; Saunders, 1992) This was further discussed in the August 1990 Booz, Allen and Hamilton document, "Space Station Freedom Program Integrated Logistics Support

Assessment: FINAL REPORT." In addition, the challenge facing the space station program was of such significance that it became the basis for the mathematical examples presented in Sherbrooke's monograph *Optimal Inventory Modeling of Systems* (1992).

The theoretical underpinning for such work derives from Palm's Theorem, which states:

> If demand for an item is a Poisson process with annual mean m and if the repair time for each failed unit is independently and identically distributed according to any distribution with mean T years, then the steady state probability distribution for the number of units in repair has a Poisson distribution with mean mT. (Sherbrooke, 1992:21)

This work presents the notion of a continuous "pipeline" of resupply. The number of items (reparables) in the pipeline is strictly a function of the expected number of demands times the expected time of repair. Note that this process is dependent only on demands being generated as part of a Poisson Process. There is no limitation placed on the distribution for repair time. This research extends the use of this theorem by applying it not only to reparables, but also to consumables, where the number of orders "in the pipeline" is then a function of expected demands times expected leadtime. The operationalization of this concept is further discussed in the following chapter.

Simulation -- Use, and Verification and Validation

The literature identifies several means of analyzing inventory problems. Each method has strengths and limitations, making their use more suitable to some forms of analysis than others. Simulation has proven itself effective in a variety of applications,

where there exists a need to represent in some form the interactions of real world problems. (Schriber, 1991: 4) In fact, the Department of Defense makes use of simulations in a myriad of ways, ranging from software simulations of aircraft maintenance activities, to hardware simulations such as flight simulators, to real-world simulations of wartime conditions involving thousands of military members in mock combat, or in short "Anything short of warfare is simulation." (Department of Defense, 1996: 3-1)

Thomas Schriber argues that simulation bridges the gap between experimentation on the "real system" with its inherent realism, and pure mathematical modeling, and the "increasing abstraction" necessary. (Schriber, 1991: 5) Law and Kelton further expand on the fit of simulation, pointing out that simulation is appropriate when the system being modeled is highly complex. As they note, "Many systems are highly complex, so that valid mathematical models of them are themselves complex, precluding any possibility of an analytical solution." (Law and Kelton, 1991: 6) Finally, Richard Tersine notes that simulation is useful when it is desirable to experiment with a system, and echoes the view that it is most appropriate when the system is sufficiently complex. (Tersine, 1994: 508)

The above quote alludes to another pressing issue, that of the verification and validation of any model, be it a mathematical or simulation approach. The Department of Defense, due to the high level of reliance upon modeling and simulations, has placed sufficient concern on ensuring that models developed are verified and valid, and in certain instances, accredited and/or certified for further use. (DoD, 1996)

Verification is defined in one source as "the task of ensuring that the model behaves as you intended" while the same source defines validation as "the task of ensuring that the model behaves the same as the real system." (Kelton, Sadowski and Sadowski, 1998: 444). Alternatively, these are defined by the DoD as:

> Verification—The process of determining that a model implementation accurately represents the developer's conceptual description and specifications
>
> Validation—The process of determining the manner and degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model (DoD, 1996: 3-3)

This definition is sufficiently broad in scope as to encompass the wide range of modeling, yet focused to ensure the needs of the customer are met. It is this definition that will be used in this research given the nature of the research question.

Law and Kelton identify 8 techniques for verification. (Law, et.al., 1991: 302) The DoD dedicates several chapters to the techniques used for both verification and validation. Other texts provide similar "laundry lists" of techniques and approaches. While each of these lists is in a sense unique, they all touch on the same approaches. These techniques are perhaps best summarized by the following chart from the DoD VV&A guide:

Verification and Validation

- **Informal**
  - Audit
  - Desk Checking
  - Face Validation
  - Inspections
  - Reviews
  - Turing Test
  - Walkthroughs
- **Static**
  - Cause-Effect Graphing
  - Control Analysis
    - Calling Structure
    - Concurrent Process
    - Control Flow
    - State Transition
  - Data Analysis
    - Data Dependency
    - Data Flow
  - Fault/Failure Analysis
  - Interface Analysis
    - Model Interface
    - User Interface
  - Semantic Analysis
  - Structural Analysis
  - Symbolic Evaluation
  - Syntax Analysis
  - Traceability Assessment
- **Dynamic**
  - Acceptance Testing
  - Alpha Testing
  - Assertion Checking
  - Beta Testing
  - Bottom-Up Testing
  - Comparison Testing
  - Compliance Testing
    - Authorization
    - Performance
    - Security
    - Standards
  - Debugging
  - Execution Testing
    - Monitoring
    - Profiling
    - Tracing
  - Fault/Failure Insertion Testing
  - Field Testing
  - Functional (Black-Box) Testing
  - Graphical Comparisons
  - Interface Testing
    - Data
    - Model
    - User
  - Object-Flow Testing
  - Partition Testing
  - Predictive Validation
  - Product Testing
  - Regression Testing
  - Sensitivity Analysis
  - Special Input Testing
    - Boundary Value
    - Equivalence Partitioning
    - Extreme Input
    - Invalid Input
    - Real-Time Input
    - Self-Driven Input
    - Stress
    - Trace-Driven Input
  - Statistical Techniques
  - Structural (White-Box)
    - Branch
    - Condition
    - Data Flow
    - Loop
    - Path
    - Statement
  - Submodel/Module Testing
  - Symbolic Debugging
  - Top-Down Testing
  - Visualization/Animation
- **Formal**
  - Induction
  - Inference
  - Logical Deduction
  - Inductive Assertions
  - Lambda Calculus
  - Predicate Calculus
  - Predicate Transformation
  - Proof of Correctness

Figure 2-1 A Taxonomy of Verification and Validation Techniques (DoD, 1996: 4-2)

One final note. The literature on verification and validation makes it clear that not all techniques are necessary, or even appropriate, for all models. It is a part of the

ongoing process to assess what tools to use to achieve a sufficient comfort level for the analysis being conducted. (Law, et.al., 1991: 300)

Relating the Literature to the Research Problem

Most of the research into multi-echelon inventory problems has focused on optimization of ordering policies assuming at all times that each retail level establishment is independent and identically distributed (iid) and follows identical ordering policies. This is not the question under consideration here. The particular question in this research focuses on describing the interplay between varied ordering policies and their resulting impact on customer service levels. As such, it is not appropriate to use a mathematical modeling (optimization) approach. We are not actually seeking an optimal solution in this effort, but rather wish to describe what is occurring, and a mathematical approach takes "no account of risk and uncertainty in their formulation" (Tersine, 1994).

As noted previously, research does indicate that aggregation of retail demands can lead to fluctuations, or demonstrate a bullwhip effect, in the demands seen at the wholesale level. This research focuses on problems at the wholesale establishment in predicting their own service levels to an aggregated retail establishment. One can see in the notional chart at Figure 2-2 that in DLA's case this metric is not out of control and is in fact consistently close to the target levels.

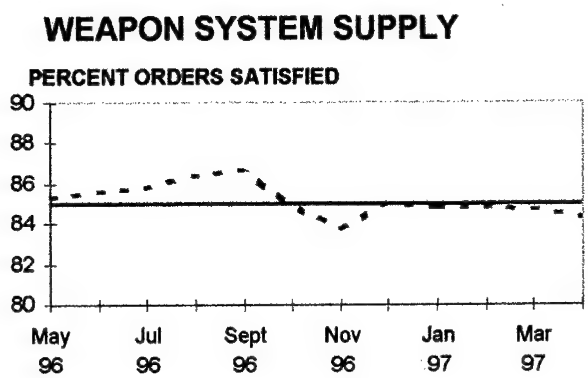

Figure 2-2

DLA is concerned with the service level impacts at the retail level, or more specifically at the retail level aggregated by service, and therefore by ordering policy. No known literature has followed this approach. Current approaches predominantly focus on achieving service target levels and constancy at the aggregate, and not for specific customers. The general assumption seems to be that the retailer's policies are effective at meeting their service levels regardless of the actions and policies of other retailers and therefore are not considered. The overlay of the application of varied ordering policies by service further complicates the analysis.

The inventory theoretic literature concerning the Normal approximation shows that this assumption could conceivably have a greater impact on the realized service levels than DLA currently understands. If the demand patterns for like items are not identical across the customer base, then it is conceivable that the convolution of demand and lead-time is different for each customer segment. This could explain the variation in

service levels noted. For purposes of this study, this effect will be minimized by selecting iid random variables for each customer base.

It is worth noting here however that the variation induced by the different ordering policies in itself could be creating the wide variance in service levels. The continuous review policy holds the order quantity constant, while the actual time between demands is random. On the other hand, the periodic review policy holds the time between demands relatively constant (as some multiple of the review period length) while varying the ordering quantity. Finally the instant reorder approach follows a random demand pattern identical to the customer demand pattern, and the order size is held to a constant quantity of one. Given this then, it is highly likely that different probability density functions are represented. The problem is then made manifest by the traditional approach followed by most if not all firms in assuming normality in computing the safety stock. This research approach will assume normality in an effort to most closely represent the decisions likely seen in practice.

Chapter 3

METHODOLOGY

This chapter presents the methodology followed in the conduct of this research. This includes the decision to use simulation and the approach followed as well as the justification and selection of the probability distribution functions representing lead time and demand. Additionally, this chapter presents the algorithms selected for determining the safety stock levels, setting the continuous and periodic review policies, and for following the "just in time," or instant reorder heuristic. This chapter discusses the assumptions used in the development of this model. Also, this chapter familiarizes the reader with the specific tools selected for the modeling approach, and then finally limitations of this methodology are outlined.

Simulation Technique and Approach

As noted in the literature review in Chapter Two, much of the work in multi-echelon inventory theory focuses on identical retail establishments allowing for the collapsing of the parallel relationships into a serial relationship. That approach provides a more computationally tractable model that can more readily be solved using analytic tools such as mathematical programming or probability

theory approaches. In addition, past research has tended to focus on providing optimal answers to given research questions and thus the aforementioned tools are appropriate.

This particular research is descriptive as well as prescriptive in nature, seeking to explain interactions given the unique situation when the assumption of identical retailers is not valid. Given this, it seems that a more appropriate means of conducting this research is through the use of discrete event simulation.

One additional benefit of this approach is that decision-makers can see the relationship between the system modeled and the simulation model, enhancing the face validity of any conclusions reached. When decision-makers can identify with the stages of the model and relate it to concepts with which they come in daily contact, they are more likely to accept the results than when it is perceived as a purely mathematical exercise. Finally, the use of this approach allows for additional "what-if" analysis allowing for a transition from a descriptive to a potentially prescriptive approach once the system is better understood.

The approach followed in developing this model is to consider those variables of interest, and to control for those variables that tend to confound the problem. Specifically, while there are other considerations and events that come to play in any supply chain and inventory system, it is best in the interests of this research question to confine the model to the most relevant variables.

Thus the decision was made to consider three retail establishments in this model each representing the three different ordering policies under consideration.

While it is recognized that typically there exist many retail establishments following the similar ordering policies, this is consistent with past modeling approaches noted in the literature review. Specifically, we assume that the retailers that have the same ordering policy, and have identical, independently distributed demand patterns, that can be collapsed into a serial relationship.

The lead times for the wholesale warehouse and for the supplier are also simplified. In these instances, the lead-time combines the administrative and logistics (transportation) delay times. While it is recognized that various aspects of order processing, warehousing and transportation contribute to the variance in delivery speed, it is assumed that such variation all contributes to the lead-time probability distribution in use. The object oriented portion of the model is represented at Appendix D.

In conducting the analysis, a sensitivity analysis approach is followed. This is done by varying the mean and variance of the arrival time of customers. Such an approach provides evidence of the potential effects on service levels as these variable relationships change. Note that changes to demand parameters are, in effect, similar to changes in order quantity (for continuous review) or changes in the lead time parameters. Each of these are inter-related with P2 service levels as noted by Silver, et. al.. (p. 269) As noted in the literature review, understanding the shape of the distribution becomes more important as the variability of the convolution of lead-time and demand increases.

Probability Distribution Functions

Three theoretical distributions are under consideration in this model. The first distribution combination is the Exponential/Poisson distribution. Exponential is used to model the inter-arrival time of the customers (demand) thereby modeling a Poisson distribution of demand, while the exponential distribution is used to model the lead times incorporated in the model. This combination was selected based on the initial assumption that the research is considering electrical aircraft components, which have been demonstrated to fit a theoretical exponential distribution for mean time between failure (MTBF) computations. The explicit assumption here is that, for these items, failures necessitates a remove and replace action and thus the mean time between failure is correlated to the mean time between demands. In addition, the exponential distribution was selected based on the premise that most deliveries are scheduled for next day, or second day service, while it is possible for there to be extended delays (for a variety of reasons) and therefore an exponential pattern captures such a distribution.

The second approach is to assume a normal distribution for the convolution of lead-time and demand. The does lead to a potential skewing of the data, and can result in other than expected service levels. This assumption is made, however, since it is the assumption most often made in practice due to the complexity involved in computing lead time demand probability distributions.

Algorithms and Heuristics

The customer service level P_2 is selected for this model. The P_2 criterion is defined by Silver, et. al, as "the fraction of customer demand that is met routinely; that is, without backorders or lost sales." (1998, p. 245) This approach is used to identify the number of customer demands that are able to be filled when requested. Research by Tyworth identifies several reasons for using this criterion.

> First, it is widely used in the distribution setting. Second, it is well suited to the continuous review model. Third, it captures the effect of lot size on safety stocks. Fourth, it is equivalent to the unit short per unit time (B_3) shortage criterion. (Tyworth, 1997.)

P_2 is an appropriate measure in the context of this research because we are concerned with both whether stockouts occur but also the number of customer demands that are not met. This is an especially appropriate measure given that all missed sales are backordered, and the P_2 criteria can be viewed as tracking the ratio of orders filled versus backordered. Additionally Silver, et. al., note that the P_2 criterion is a popular one with practitioners and thus further enhances the face validity of the research. It is known from experience that the Department of Defense decision makers focus on such measures. Consequently, results from this approach are also more readily compared to existing operations.

The traditional decision rule is followed in determining the reorder point and safety stock for the continuous review policy (s,Q). That is, normality of lead time demand is assumed, given that the policies in question in the Department of Defense typically follow this assumption as standard practice. In this instance, the

value of Q is identified as an independent variable and is assumed to have been predetermined.

Given this, we use the following notation and formulations:

$$\mu_x = \mu_L * \mu_D$$
$$\sigma_x^2 = (\mu_L * \sigma_D^2) + (\mu_D^2 * \sigma_L^2)$$
$$G(k) = (1 - P_2)Q / \sigma_x$$
$$z = \sqrt{\ln \frac{25}{G(k)^2}}$$
$$k = \frac{a_0 + a_1 z + a_2 z^2 + a_3 z^3}{b_0 + b_1 z + b_2 z^2 + b_3 z^3 + b_4 z^4}$$
$$SS = k\sigma_x$$
$$ROP = SS + \mu_x$$
$$ES = (1 - P_2)$$

Procedure 3-1

Where:

μ_x =Mean Demand over Lead-time
σ_x =Standard Deviation of Demand over Lead-time
L = Lead-time
D = Demand
Q = Order Quantity
SS = Safety Stock
K = Safety Factor
ROP = Reorder Point, or s
ES = Expected Shortage
P_2 = Service Level Policy (percentage demand satisfied)
G(k) = "a special function of the unit normal loss function (mean 0, standard deviation 1) variable." (Silver, et.al.., 1997:255)

The average demand during lead time (μ_x), and the standard deviation of demand during lead time (σ_x), are calculated using the commonly accepted

formulas noted above (Silver, et.al, 1998: 283). As noted by Mentzer and Krishnan (1985) this approach is the one presented in most inventory and logistics texts.

G(k) is the unit normal function that allows us to relate the distribution of demands over lead time to the standard normal distribution (mean = 0, standard deviation = 1). This equation is:

$$G(k) = \int_k^{\infty} (u_0 - k) f_u(u_0) du_0$$

Equation 3-1 (Silver, et al., 1998:721)

The G(k) is not easily integrated and thus numerical approximations have been developed. These approximations are calculated through the use of z and the equation for calculating k. The values for z and k are calculated using an approximation presented by Waissi and Rossin (1996). The values for a_i and b_i are constants and are reflected below in the Visual Basic for Application code as presented by Silver (1998: 736).

The actual Visual Basic for Applications code implementing this formulation is:

```
      CRMLTD = ((ActualLTMean) * DailyDemand)
      CRSLTD = (ActualLTMean * (DailyVariance)) + (DailyDemand ^
2 * (ActualLTStdDev) ^ 2)

      CRgk = (1 - ServiceLevel) * CROrderQuantity / Sqr(CRSLTD)
      CRZ = Sqr(Log(25 / CRgk ^ 2))
      CRk = ((-5.3925569) + (5.6211054 * CRZ) + ((-3.883683) *
(CRZ) ^ 2) + 1.0897299 * CRZ ^ 3) / (1 + (-0.72496485 * CRZ) +
(0.507326622 * (CRZ) ^ 2) + (0.0669136868 * (CRZ) ^ 3) + (-
0.00329129114 * (CRZ) ^ 4))
```

```
    CRSafetyStock = (CRk * Sqr(CRSLTD))
    ROP = smutils_XL.WorksheetFunction.RoundUp((CRSafetyStock +
CRMLTD), 0)

    If ROP < 0 Then

        ROP = 0

    End If
```

The periodic review policy (R, S) can be viewed as exactly equivalent to the continuous review policy, if certain substitutions are made (See Table 3-1). It is necessary to substitute the demand over the review period (DR) for order size Q, and the order up to quantity S for the reorder point *s*. Additionally, it is necessary to substitute the sum of the expected value of Lead Time (L) and the Review Period (R) for lead-time. (Silver, et.al., p. 275) These substitutions allow for the computation of the "order up to quantity" S and the appropriate safety stock levels. Because of this equivalence we can use the same safety stock level computational techniques, considering that safety stock is a function of lead time and daily demand.

(s,Q)	(R, S)
s	S
Q	DR
L	L+R

Silver, et, al, 1998. P. 275

Table 3-1

Following this approach then, we assume that the review period is predetermined. Our formulation then:

$$\mu_x = \mu_{R+L} * \mu_D$$
$$\sigma_x^2 = (\mu_{R+L} * \sigma_D^2) + (\mu_D^2 * \sigma_{R+L}^2)$$
$$G(k) = (1 - P_2) DR / \sigma_x$$
$$z = \sqrt{\ln \frac{25}{G(k)^2}}$$
$$k = \frac{a_0 + a_1 z + a_2 z^2 + a_3 z^3}{b_0 + b_1 z + b_2 z^2 + b_3 z^3 + b_4 z^4}$$
$$SS = k\sigma_x$$
$$S = RD + \mu_x + SS$$
$$ES = (1 - P_2)$$

Procedure 3-2

Where:

μ_x =Mean Demand over Lead-time
σ_x =Standard Deviation of Demand over Lead-time
L = Lead-time
D = Demand
S = Order Up To Quantity
R = Review Period
SS = Safety Stock
K = Safety Factor
ROP = Reorder Point, or s
ES = Expected Shortage
P_2 = Service Level Policy (percentage demand satisfied)
G(k) = "a special function of the unit normal loss function (mean 0, standard deviation 1) variable." (Silver, et.al.., 1998:255)

The actual Visual Basic for Applications code implementing this formulation is:

```
PRLTSTD = PRLTStdDev
LTandRP = 1 * ReviewPd + 1 * PRLTMean
```

```
      PRMLTD = (PRLTMean * DailyDemand)
      PRSLTD = (PRLTMean * (DailyVariance)) + (DailyDemand ^ 2 *
(PRLTSTD ^ 2))

      PRQ = (ReviewPd * DailyDemand)
      StockoutLevel = 1 - ServiceLevel
      PRgk = (StockoutLevel) * (PRQ / (PRSLTD ^ 0.5))
      PRZ = Sqr(Log(25 / PRgk ^ 2))
      PRk = ((-5.3925569) + (5.6211054 * PRZ) + ((-3.883683) *
(PRZ) ^ 2) + 1.0897299 * PRZ ^ 3) / (1 + (-0.72496485 * PRZ) +
(0.507326622 * (PRZ) ^ 2) + (0.0669136868 * (PRZ) ^ 3) + (-
0.00329129114 * (PRZ) ^ 4))

      PRSafetyStock = (PRk * Sqr(PRSLTD))

       PR_S = smutils_XL.WorksheetFunction.RoundUp(((ReviewPd *
DailyDemand) + PRMLTD + PRSafetyStock), 0)
```

The instant reorder policy is a special case of the continuous review policy, where Q is equal to 1 (s-1,S). In this case, we find that the computations take into account the amount of stock "in the pipeline" and we can expect deliveries of orders to follow a distribution identical to the distribution of demands. This is Palm's Theorem and is described in literature referencing the removal, repair and replacement of repairable parts as noted previously on page 15. (Sherbrooke, 1992:21; Silver, et. al., 1998: 505)

This is operationalized in this model by assuming the convolution of lead time demand is a Poisson distribution with a lambda equal to the expected demand times the expected lead time. This approximation matches closely the results achieved by computing the expected service level, or expected fill rate (EFR) by using:

$$EFR = PR\{DI \leq s-1\}$$

Equation 3-2

where the expected fill rate is equal to the probability that the amount on hand is greater than, or equal to the stock level (s).

This model then requires establishing an initial inventory point (stock level, s) equal to the reorder point in the continuous review model. Computations are thus fixed based on the order size of 1, and the model does not consider a reorder point, but rather will always place an order for replenishment whenever a demand is received. Note that this assumes the change in computation of convolution of lead time demand, assuming it is now a Poisson distribution, with lambda equal to $\mu_D * \mu_L$ (the expected demand and expected lead time.)

The adjusted formulation is as follows:

$$\mu_x = \mu_L * \mu_D$$
$$\sigma_x^2 = \mu_L + \mu_D$$
$$G(k) = \frac{(1-P_2)}{\sigma_x}$$
$$z = \sqrt{\ln \frac{25}{G(k))^2}}$$
$$k = \frac{a_0 + a_1 z + a_2 z^2 + a_3 z^3}{b_0 + b_1 z + b_2 z^2 + b_3 z^3 + b_4 z^4}$$
$$SS = k\sigma_x$$
$$ROP = SS + \mu_x$$
$$ES = (1-P_2)$$

Procedure 3-3

Again, the Visual Basic for Applications operationalization of these formulas is:

```
IRMLTD = (DailyDemand) * DepotMeanLT
```

```
   IRSLTD = IRMLTD

   IRgk = (1 - ServiceLevel) * IROrderQuantity / Sqr(IRSLTD)
   IRZ = Sqr(Log(25 / IRgk ^ 2))
   IRk = ((-5.3925569) + (5.6211054 * IRZ) + ((-3.883683) * (IRZ)
^ 2) + 1.0897299 * IRZ ^ 3) / (1 + (-0.72496485 * IRZ) +
(0.507326622 * (IRZ) ^ 2) + (0.0669136868 * (IRZ) ^ 3) + (-
0.00329129114 * (IRZ) ^ 4))

   IRSafetyStock = (IRk * Sqr(IRSLTD))
   IROP = smutils_XL.WorksheetFunction.RoundUp((IRSafetyStock +
(DailyDemand) * DepotMeanLT), 0)

   If IROP < 0 Then
      IROP = 0
     End If
```

Given that all orders are placed immediately the inventory level may fluctuate but on average should be maintained at a level consistent with the service policy level.

In each of these policies when the variation of lead time (σ_L) is large compared to the order size (Q), the existing equation double counts backorders resulting in a higher computed safety stock than is required. This then results in greater service level than originally targeted. To compensate for this, it is necessary to use a more accurate formula for when Q/σ_L is small. This formula is:

$$G(k) - G(k + Q/\sigma_L) = Q/\sigma_L\,(1-P_2)$$

Equation 3-3

This equation is approximated for each of the reordering policies. In operationalizing this approach, the modified formula is used when the Q is less than σ_L. A sample of the code from the continuous review modeling is presented.

The code is nearly identical for each of the three policies. The Visual Basic for Applications code is shown:

```
      If ((CROrderQuantity) / Sqr(CRSLTD)) < 1 Then
            CRk = CRk + ((CROrderQuantity) / Sqr(CRSLTD))
            p_CRk = 1 -
smutils_XL.WorksheetFunction.NormSDist(CRk)
            f_CRk = (1 / (Sqr(2 * 3.1415926))) * Exp(-(CRk ^ 2) /
2)
            CRgkNEW = f_CRk - (p_CRk * CRk)
            CRgk = (1 - ServiceLevel) * ((CROrderQuantity) /
CRSLTD ^ 0.5) + CRgkNEW
            CRZ = Sqr(Log(25 / CRgk ^ 2))
            CRk = ((-5.3925569) + (5.6211054 * CRZ) + ((-
3.883683) * (CRZ) ^ 2) + 1.0897299 * CRZ ^ 3) / (1 + (-0.72496485
* CRZ) + (0.507326622 * (CRZ) ^ 2) + (0.0669136868 * (CRZ) ^ 3) +
(-0.00329129114 * (CRZ) ^ 4))

      End If
```

The operating assumption throughout the model is that the warehouse also follows a continuous review policy (s, S), based on the aggregation of demands and demand distributions rather than the (s, Q) policy followed in the traditional continuous review model. One of the main assumptions of a continuous review (s, Q) policy is the assumption that demand is in unit sized lots. Given that demand at the depot tends to be "lumpy," that is, demands arrive in order quantity sizes (either Q, or S) then this assumption no longer holds. Without this assumption, it is possible for demands to arrive that place the stock level below the reorder point. Therefore, it is necessary to provide for an adjustment to order quantity sizing, otherwise the stock levels will gradually deplete. The adjustment, simply put, is:

$$S = s + Q$$

Where S is the actual order quantity, s is the computed ROP minus the actual stock on hand, and Q is the preferred, or optimal, order quantity (Silver, et.al. 1992:332).

Otherwise, the formulas for computing the policy are identical to those listed above.

$$\mu_x = \mu_L * \mu_D$$
$$\sigma_x^2 = (\mu_L * \sigma_D^2) + (\mu_D^2 * \sigma_L^2)$$
$$G(k) = (1 - P_2)\frac{Q}{\sigma_x}$$
$$z = \sqrt{\ln \frac{25}{G(k)^2}}$$
$$k = \frac{a_0 + a_1 z + a_2 z^2 + a_3 z^3}{b_0 + b_1 z + b_2 z^2 + b_3 z^3 + b_4 z^4}$$
$$SS = k\sigma_x$$
$$ROP = SS + \mu_x$$
$$ES = (1 - P_2))$$

Procedure 3-4

Again, to account for the possibility that Q/σ_L may be small, the formula mentioned above is included.

Assumptions

As mentioned previously, assumptions are necessary to achieve a parsimonious model. Certain assumptions have been identified in the preceding paragraphs.

The specific assumptions in this model are:

- A multi-echelon, three tier model, with each retailer following one of:
  - Continuous review policy
  - Periodic review policy
  - Instant reorder policy
- An exponential pattern of mean time between failures (MTBF) leads to an exponential mean time between demand (MTBD) which equates to a Poisson distribution of demands.
- Demand and Lead-time are independent, identically distributed random variables following theoretical distributions where the mean and variance are easily estimated.
- The convolution of Lead-time and demand follow a normal distribution.
- Orders are processed and sent on a first come/first served basis.

Tools

This simulation is based on the Siman/Arena program, from Systems Modeling, Inc (core simulation engine, and output analysis). Arena is a graphically driven, object-oriented simulation programming language. This interface is based on the original text-based SIMAN simulation programming language. The graphical simulation model is included as Appendix D. The text-based portion of the program is included at Appendices A and B. The model file represents the actual logic of the program, while the experiment file contains the various conditions of the experiment.

In addition, Arena supports Microsoft's Visual Basic for Applications (VBA). The VBA code for each of the models is included in Appendix C. This code provides the interface for the user to adjust the operating parameters at run time, and establishes the links to Excel. Also, VBA provides an opportunity for greater flexibility in the model design and operation than is immediately available through the SIMAN/Arena commands. Finally, Arena can also be used in conjunction with a "viewer" program that will allow for the running of simulations in a "runtime only" environment. Combining the viewer with the flexibility provided by using VBA has allowed for the creation of flexible models, capable of being run and generating data over a range of parameter settings without the need for the full version of Arena.

Microsoft Excel 97 is used for computational assistance and for output analysis. Through the use of VBA, the SIMAN Arena program can directly access functions contained in Excel. This greatly enhances the ability to compute the reorder points and safety stock. VBA also acts as a conduit directing the various outputs from the simulation to Excel workbooks. This provides a readily accessible means of conducting statistical analysis on the results of the simulation runs through the use of built-in statistical tools. Finally, Excel provides extensive charting capabilities useful both in analyzing and understanding the data, as well as in presenting the findings.

Approach

To adequately assess the effectiveness of each of the reordering policies, and to provide a foundation for comparison of each policy independently with the results achieved when interacting, it was decided to develop four models. Each reordering policy was developed separately, and run to validate the modeling approaches used, and verify that these approaches perform as expected. The approaches were then combined into one model. This model was then tested to ensure that each of the policies continued to perform appropriately. This fully developed model was then used to collect the data for the analysis. For the analysis of the individual policies, the competing policies were "turned off" while

the policy of interest was run. After each of the three individual policies were run, the full model was run, with all three policies active.

Verification and Validation

As noted previously, it is necessary to perform an assessment of the model to determine if it is internally consistent, performs as expected, and is an adequate representation of the "real world" for the purposes for which it is intended. This process was tailored to meet the needs and purposes of this research. Specifically, this model seeks to determine interactions compared to a theoretical base. As such, this research seeks validation against the commonly accepted theoretical constructs and thus is only as applicable to real world constructs as is the accepted theory.

This research implemented to some modest degree most of the practices identified in the taxonomy developed by the DoD presented in Chapter 2: These include desk checks, debugging of the code, comparisons to alternative simulations, and emphasis on face validity. Presentation of the results in Chapter 4 summarizes the results of the verification and validation of the model, as the various research questions are tested through analysis of the results.

As an integral part of the verification and validation process, it was decided that each of the reordering policies would be tested separately, and the results then compared to the theoretically predicted values. This step was inserted

due to the concern about the impacts of assuming normality of lead time demand when such an assumption may not be valid. Additionally, to moderate and control for the possible deleterious effects of this assumption, the results for each of the policies from the full model will be tested against the actual performance of those policies when run without interactions with the other policies.

The Simulation Procedure

As mentioned previously, in order to test the hypotheses it was necessary to first develop one complete model, and then distill that model into the component ordering policies. In this way, we are able to control for the general configuration of the model by ensuring that the identical code is used in each of the models. This provides a level of confidence in our ability to draw conclusions between the various hypotheses since each process is identical, with only the specific interactions removed.

In addition, since our desire is to assess the differences between the models, it seemed prudent to control for the random numbers generated. Thus, the random number streams were controlled using common random number streams for each of the random number generators. That is, each random "event" (continuous review customer demands, or demand lead times, for example) were each assigned independent random number streams. This synchronizes the

random numbers across the different runs for each of the models such that any changes introduced are the result of the interactions and not the results of the randomness of the model itself. This approach has been shown to reduce the variability introduced by variables outside the variables of interest and thus improve the effectiveness of the model and reduce the number of replications required to attain satisfactory results.(Kelton, et. al., 1998:410-418)

A run time of 5000 periods (including a warm up period of 1000 time periods) was selected. Each period, while in a sense "valueless," is seen to represent one day of operation. This length was chosen to allow sufficient time for the collection of adequate statistical data. The startup conditions of the model were carefully chosen with a starting inventory in excess of the reorder point to allow for operations of the model prior to the need for an order being placed. Specifically, this avoided a condition where the simulated retailers would have to "catch up" during the early stages of the replications.

The warm up period of 1000 was chosen after review of a sample of the various graphical outputs from SIMAN/ARENA for the warehouse levels, and backorder levels. While there was no significant variation observed over time (no ramping up, or decreases) it was deemed prudent to allow for the system to reach a steady state.

The decision was made to conduct 30 replications for each parameter set. This was selected to provide a sufficient number of runs to allow for statistical analysis assuming large sample size. Again, this was a sample size in excess of

minimum sample size recommended following standard methods for determining sample size. The commonly accepted practice for determining sample size was followed. This includes conducting a small number of sample runs, and then determining the mean and variance of those runs. (Centeno, et.al., 1998) These values are then used to calculate *n* by using the equation:

$$n = \frac{z_{\alpha/2}^{2}\sigma^{2}}{d^{2}}$$

Equation 3-4

When taking these values and starting with an assumption that n=30, it was found that that sample size was sufficient to allow for precision to ±0.2 percent of the expected mean, at the 95% confidence level.

The combination of a run length of 5000 periods, along with 3 replications were sufficiently large to allow for adequate analysis, while at the same time not proving unduly burdensome on the computational capability available. Samples runs were conducted with longer run lengths, and/or larger numbers of replications, but no significant change in mean or variance were noted.

The independent variables of interest in this research are the customer inter-arrival times, and the target (P2) service levels. The inter-arrival times were varied over the range of one demand a day up to one demand every 20 days, incrementing by one. This simulates the relationship for moderate to slow moving items. This seemed appropriate since any (s-1,S) ordering policy loses

ties to reality when orders are with any frequency greater than one day. Additionally, the service levels were fixed at 98%, 95%, 92%, and 85%. These were selected to reflect policy decisions likely seen in the operational world. Given these two independent variables, and the decision to conduct 30 replications for each parameter set, one can see the large number of actual simulation replications that were necessary. In fact, to complete the analysis over 9600 replications were conducted, contained within 320 runs.

The models were run with a fixed assumed mean and variance of lead-time for both the time to fill an order from depot, and the time required for a supplier to fill an order placed by the depot. These were modeled as exponential processes but the parameter of that process was not changed. Additionally, the order quantity for the continuous review policy and depot were fixed.

One additional note. It was mentioned above that the periods of time in the simulation were "value-less." This is important in understanding the results of the simulation. While we are assuming the time periods represent one day of operation, this is more for conceptual understanding than an actual inherent relationship to the model. What is ultimately of importance given this formulation is the time relationship between customer/demand arrivals and the lead-time. It is this time based relationship that is ultimately being tested.

Limitations of the Research

First, this research is based on simulation rather than mathematical modeling. As such this research cannot find optimal solutions. This research has been designed to work with this inherent limitation. The intent is to leverage the benefits of simulation, including the ability to conduct what-if analysis, the complexity that can be accommodated, and the broad range of data that can be collected.

As with any research, this research is limited in the degree to which generalizations can be made beyond the parameters considered and the assumptions made. The assumptions placed on the model, including the decisions made for probability distributions, lead times, and order size, are all limiting factors in using this model as a predictive tool. For instance, the decision to only consider exponential distributions for the inter-arrival time of demand and for lead times limits the ability to generalize the findings of this study.

This research assumed the depot followed a modified reordering policy accounting for the lumpiness of demand when orders placed with the depot are not unit sized. This decision, while theoretically appropriate, may not accurately reflect the operations of wholesalers/depots in the field.

Additionally, the simulation is based on the application of the theoretical constructs for inventory theory, and may not represent actual practice seen in the

field. Finally, it is important to note that there may be other influences at work in the supply chain that impact performance resulting in higher or lower service levels than those identified through this research. Such influences could include, but would by no means be limited to, communications flows, interjections of decision makers, expedite decisions, and special orders for unique situations.

CHAPTER 4

FINDINGS AND ANALYSIS

The past three chapters presented the research questions, reviewed the pertinent literature, and discussed the general methodology followed in this research. This chapter refines the research questions, identifying the specific hypotheses to be tested. In addition, this chapter presents the specific analytical techniques used to determine the effectiveness of the models. Finally, the results of the hypotheses testing are presented.

Research Questions and Hypotheses

As noted previously, this research focused on the potential interactions of three different ordering policies, an (s,Q) continuous review policy, an (R,S) periodic review policy, and an (s-1,S) special case of the continuous review policy. The research questions under consideration regarding these three policies were:

1. Does a difference exist between expected and realized customer service levels for the individual retail establishments? This question can be considered regardless of whether each retail establishment has chosen identical customer service targets or not. This question is treated in two parts.

   1A. First, given the parameters and assumptions used, does each individual policy meet the theoretically expected values, and;

1B. Second, when the fully integrated, and interactive model is run, does the performance of each ordering policy meet the theoretically expected values?

2. If a difference exists between the theoretical expected value and that actually achieved, does a difference then exist between the performance of a given policy when no competing policies exist and when the fully interactive model is used?
3. Do varied ordering policies at the retail level result in differing service levels between the retail establishments? This question is applicable when the retail establishments have each established their safety stock and ordering quantities based on identical service level goals.
4. If a difference exists between expected and realized customer service levels, does one retail level ordering/review policy tend to outperform other policies? This question takes this process from a purely descriptive research effort and begins to look at the prescriptive aspects.

To conduct this research, and to ensure the validation of the model in use, the model was broken in to the three components, with each policy being run separately. This provided for several verification and validation checks. First, it allowed for the code to be debugged in a modular fashion, ensuring that the component code performed as was intended. Second, it allowed for (as noted in Research Question One) an assessment to be made as to whether the models would actually perform as theoretically expected given the parameters used and the assumptions made.

From this then, two sets of hypotheses were developed for testing, with each set consisting of three hypotheses representing the three different ordering policies under consideration.

The first question under consideration is whether the individual models accurately model the theory. In this case the tests of hypotheses will be a basic test for a single mean, when the variance is unknown, using a one tailed t-test. The one-tailed test is used since the theoretical constructs for service level inventory policy are designed to achieve a target level, or greater. The hypotheses under consideration are:

$1A_p$ -- H_0: The mean service level value achieved from the periodic review model *is greater than or equal to* the expected value.

H_A: The mean service level value achieved from the periodic review model *is less than* the expected value.

This is expressed as:

$$H_0 : \bar{x}_p \geq \mu_p$$
$$H_A : \bar{x}_p < \mu_p$$

Equation 4-1

$1A_c$ -- H_0: The mean service level value achieved from the continuous review model *is greater than or equal to* the expected value.

H_A: The mean service level value achieved from the continuous review model *is less than* the expected value.

This is expressed as:

$$H_0 : \bar{x}_c \geq \mu_c$$
$$H_A : \bar{x}_c < \mu_c$$

Equation 4-2

$1A_i$ -- H_0: The mean service level value achieved from the instantaneous replenishment review model *is greater than or equal to* the expected value.

H_A: The mean service level value achieved from the instantaneous replenishment review model *is less than* the expected value.
This is expressed as:

$$H_0 : \overline{x}_i \geq \mu_i$$
$$H_A : \overline{x}_i < \mu_i$$

Equation 4-3

Each of these hypotheses are tested across each of the two variables of interest, demand rate, and target service level.

The second question to be answered is whether the individual policies accurately reflect the theoretical results when run in the complete model. These hypotheses are nearly identical to the previous hypotheses. Again, the tests of hypotheses will be a basic test for a single mean, when the variance is unknown, using a one tailed t-test. The one-tailed test is used since the theoretical constructs for service level inventory policy are designed to achieve a target level, or greater. The hypotheses under consideration are:

$1B_p$ -- H_0: The mean service level value achieved from the periodic review policy in the full model *is greater than or equal to* the expected value.

H_A: The mean service level value achieved from the periodic review policy in the full model *is less than* the expected value.
This is expressed as:

$$H_0 : \overline{x}_{fp} \geq \mu_{fp}$$
$$H_A : \overline{x}_{fp} < \mu_{fp}$$

Equation 4-4

$1B_c$ -- H_0: The mean service level value achieved from the continuous review policy in the full model *is greater than or equal to* the expected value.

H_A: The mean service level value achieved from the continuous review policy in the full model *is less than* the expected value.
This is expressed as:

$$H_0 : \overline{x}_{fc} \geq \mu_{fc}$$
$$H_A : \overline{x}_{fc} < \mu_{fc}$$

Equation 4-5

$1B_i$ -- H_0: The mean service level value achieved from the instantaneous replenishment review policy in the full model *is greater than or equal to* the expected value.

H_A: The mean service level value achieved from the instantaneous replenishment review model policy in the full model *is less than* the expected value.

This is expressed as:

$$H_0 : \overline{x}_{fi} \geq \mu_{fi}$$
$$H_A : \overline{x}_{fi} < \mu_{fi}$$

Equation 4-6

Each of these hypotheses are tested across each of the two variables of interest, demand rate, and target service level.

The second research question focuses on the comparison between the two categories of runs (individual versus interactive). Specifically, it looks at each of the policies to determine if there is a difference between the performance of the policy in the

full model when compared with the performance of the policy when run independently. This leads to the following hypotheses:

2_p -- H_0: The mean service level value from the periodic review model is equal to the mean service level value of the periodic review policy in the full model.

H_A: The mean service level value from the periodic review model is *NOT equal* to the mean service level value of the periodic review policy in the full model.

This is represented by:

$$H_0 : \overline{x}_p = \overline{x}_{fp}$$
$$H_A : \overline{x}_p \neq \overline{x}_{fp}$$

Equation 4-7

2_c -- H_0: The mean service level value from the continuous review model is equal to the mean service level value of the continuous review policy in the full model.

H_A: The mean service level value from the continuous review model is *NOT equal* to the mean service level value of the continuous review policy in the full model.

$$H_0 : \overline{x}_c = \overline{x}_{fc}$$
$$H_A : \overline{x}_c \neq \overline{x}_{fc}$$

Equation 4-8

2_i -- H_0: The mean service level value from the instantaneous review model is equal to the mean service level value of the instantaneous review policy in the full model.

H_A: The mean service level value from the instantaneous review model is *NOT equal* to the mean service level value of the instantaneous review policy in the full model.

$$H_0 : \overline{x}_i = \overline{x}_{fi}$$
$$H_A : \overline{x}_i \neq \overline{x}_{fi}$$

Equation 4-9

The third Research Question tests whether the various policies perform identically, or whether differences exist between these policies. This requires a test across multiple means. This test is conducted as a one-way Analysis of Variance test, or an ANOVA. The result of the testing of this hypothesis will either be that there is no difference between the models, or else that at least one mean is not equal. Thus, the hypothesis to be tested is formulated as:

2_i -- H_0: The mean service levels value from the periodic review policy, the continuous review policy, and the instantaneous review model, in the full model, are all equal.

H_A: *AT LEAST ONE* of the mean service levels value from the periodic review policy, the continuous review policy, and the instantaneous review model, in the full model, is different.

This approach will lead us to the following formulation, where if we reject the null hypothesis we cannot know which mean or means is different.

$$H_0 : \overline{x}_p = \overline{x}_c = \overline{x}_i$$
$$H_A : Not\ So$$

Equation 4-10

The fourth and final Research Question seeks to determine if certain policies tend to outperform the others. This is an extension of the above, and is conducted with the same null and alternative hypotheses. In conducting this analysis, a crosswise comparison is done to determine which means are not identical. This test is conducted using the Newman-Kuels method. In this question then, we see the question formulated as:

-- H_0: The mean service level values from the periodic review policy, the continuous review policy, and the instantaneous review model, in the full model, are all equal.

H_{A1}: The mean service level values from the periodic review policy, and the continuous review policy, and the instantaneous review model, in the full model, is different.

H_{A2}: The mean service level values from the continuous review policy, and the instantaneous review model, in the full model, differ.

H_{A3}: The mean service level values from the periodic review policy, and the continuous review policy in the full model differ.

H_{A4}: The mean service level values from the periodic review policy, and the instantaneous review model, in the full model, differ.

Or expressed differently, the hypotheses are:

$$H_0 : \overline{x}_p = \overline{x}_c = \overline{x}_i$$
$$H_{A_1} : \overline{x}_p \neq \overline{x}_c \neq \overline{x}_i ; OR$$
$$H_{A_2} : \overline{x}_c \neq \overline{x}_i ; OR$$
$$H_{A_3} : \overline{x}_p \neq \overline{x}_c ; OR$$
$$H_{A_4} : \overline{x}_p \neq \overline{x}_i ;$$

Equation 4-11

Results and Findings

Research Question One:

Hypothesis $1A_p$ - Periodic Review Policy

The data derived from the simulation suggests that generally the simulations of each of the ordering policies when run independently, meet or exceed the target service level. Table 4-1 presents the results of the Periodic Review Policy, run at the 98% Service Level. This analysis was conducted by taking the grand mean and standard deviation of the thirty replications for each of the demand interarrival rates, and then conducting a one tailed t-test on that number. The t-test is appropriate since we do not know in advance the variance of the actual population. The equation for the t-test is:

$$t^{*} = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$$

Equation 4-12 t-Test Formula

For example, we see in Table 4-1, for the first row, demands arriving on average every 20 days, that the mean service level for all 30 replications was 97.1176%. The standard deviation for those 30 replications was 1.6576. Given this then, and knowing that we did indeed have 30 replications, the test statistic is computed as:

$$t^{*} = \frac{97.1176 - 98}{\frac{1.6576}{\sqrt{30}}} = -0.922015$$

Equation 4-13 - t-test for Demand every 20 Days

Here we can see that while the actual mean of 97.1176% was below the target service level of 98%, we statistically cannot reject that it is actually 98% or better. In looking at the table, one will notice several instances of demand patterns (demands at 20 through 18, 16, 15, 12, and 10) where we fail to reject the null, although the actual values are below 98%. Again, note that this is a one-tailed test, and we are determining whether or not the achieved service level is 98% *or better* and not just whether it is equal to 98% or not. This means that we fail to reject (and thus in practice, accept) the null hypothesis that we have met or exceeded the target service level, even in cases where we have exceeded the service level by several percentage points.

Demand Arrivals	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	97.1176%	1.6576%	5	-0.922015	Accept
19	0.967449	1.7082%	5	-1.272602	Accept
18	0.960083	2.1922%	5	-1.573659	Accept
17	0.950572	2.2459%	5	-2.269502	Reject
16	0.979875	1.2151%	6	-0.017752	Accept
15	0.973658	1.2747%	6	-0.861751	Accept
14	0.964011	1.4168%	6	-1.954694	Reject
13	0.980713	1.1612%	7	0.106332	Accept
12	0.971813	1.2763%	7	-1.111035	Accept
11	0.980685	1.2915%	8	0.091892	Accept
10	0.974777	1.1889%	8	-0.760952	Accept
9	0.981325	1.0582%	9	0.216957	Accept
8	0.982499	1.0615%	10	0.407711	Accept
7	0.98038	1.2739%	11	0.051617	Accept
6	0.987848	1.0080%	13	1.348597	Accept
5	0.987815	0.8752%	15	1.546565	Accept
4	0.992247	0.8257%	19	2.568976	Accept
3	0.995426	0.3513%	25	7.606379	Accept
2	0.995596	0.4131%	36	6.539511	Accept
1	0.998428	0.00196	71	16.285113	Accept

Table 4-1 - Periodic Review, 98% Service Level

The t-Test was conducted with an α=0.05. At that level, the t-score was equal to 1.70. For the one tailed test, we reject the null hypothesis if the computed test statistic is less than -1.70, otherwise we fail to reject the null. In this case then, we fail to reject the null hypothesis in all but two cases. In those two cases (demands every 17 days on average, and demands every 14 days on average) we see that the actual percent service level demonstrated in the experiment was sufficiently below 98% such that we reject the null hypothesis that it is equal to or greater than 98%.

The data in Table 4-2 show the results when the target service level is 95%. Notice that we reject the null hypothesis in two instances, when demands were arriving once every 20 days on average and every 19 days. For the rest of the simulations, we fail

to reject, and thus in practice will accept, that the service level is at or above 95%. Note again that several other demand inter-arrival rates had a demonstrated service level below 95% but not statistically significantly below 95% at an α=0.05.

Target Service Level	95%

Demand Arrivals	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	92.14%	2.74%	4	-1.810339	Reject
19	0.915439	2.50%	4	-2.394881	Reject
18	0.958585	2.29%	5	0.649332	Accept
17	0.948796	2.36%	5	-0.088197	Accept
16	0.948621	1.92%	5	-0.124644	Accept
15	0.937932	2.12%	5	-0.984158	Accept
14	0.963222	1.53%	6	1.496935	Accept
13	0.955906	1.90%	6	0.538794	Accept
12	0.937953	2.19%	6	-0.952644	Accept
11	0.959028	2.00%	7	0.780933	Accept
10	0.94919	1.89%	7	-0.074029	Accept
9	0.960046	1.57%	8	1.111467	Accept
8	0.967263	1.60%	9	1.863283	Accept
7	0.965428	1.79%	10	1.494199	Accept
6	0.962507	1.64%	11	1.318630	Accept
5	0.967779	1.58%	13	1.943240	Accept
4	0.9819	1.30%	17	4.238574	Accept
3	0.984707	0.84%	22	7.129718	Accept
2	0.986433	0.76%	32	8.301421	Accept
1	0.991614	0.005301	62	13.597612	Accept

Table 4-2 - Periodic Review, 95% Service Level

Table 4-3 and Table 4-4 each show the results when each of the inter-arrival patters was run at a 92% and 85% target service level. Notice again that in only one series we reject the null hypothesis, in practice accepting that the model performs at or above the 92% service level. Also note that we only reject the null for the runs conducted at the 85% service level for the instance when customer arrivals are on average once every 20 days.

Target Service Level	92%

Demand Arrivals	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	91.67%	0.030908	4	-0.185005	Accept
19	0.909832	0.026539	4	-0.663582	Accept
18	0.897593	0.035231	4	-1.101597	Accept
17	0.876495	0.034889	4	-2.159757	Reject
16	0.94287	0.02034	5	1.947414	Accept
15	0.934197	0.022408	5	1.097386	Accept
14	0.913978	0.024023	5	-0.434174	Accept
13	0.90232	0.027021	5	-1.133281	Accept
12	0.935534	0.022273	6	1.207996	Accept
11	0.917109	0.026673	6	-0.187702	Accept
10	0.947842	2.05%	7	2.349246	Accept
9	0.923347	0.022275	7	0.260291	Accept
8	0.936998	0.022693	8	1.297401	Accept
7	0.942034	0.020759	9	1.838380	Accept
6	0.961792	0.016512	11	4.383913	Accept
5	0.948219	0.021181	12	2.307577	Accept
4	0.960457	0.020106	15	3.485259	Accept
3	0.969536	0.013691	20	6.266783	Accept
2	0.970733	0.011711	29	7.503298	Accept
1	0.980868	0.008168	57	12.906684	Accept

Table 4-3 - Periodic Review Policy, 92% Service Level

Demand Arrivals	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	77.34%	0.057404	3	-2.311990	Reject
19	0.88029	0.045649	4	1.149287	Accept
18	0.858711	0.057659	4	0.261687	Accept
17	0.838296	0.045914	4	-0.441528	Accept
16	0.822207	0.043209	4	-1.114082	Accept
15	0.801145	0.054038	4	-1.565917	Accept
14	0.861069	0.045922	5	0.417496	Accept
13	0.877203	0.031469	5	1.497214	Accept
12	0.843288	0.03707	5	-0.313599	Accept
11	0.898485	0.032873	6	2.554654	Accept
10	0.890204	0.033574	6	2.074096	Accept
9	0.912696	0.027675	7	3.923811	Accept
8	0.879323	0.03264	7	1.556024	Accept
7	0.892875	0.030011	8	2.474470	Accept
6	0.893023	0.028016	9	2.659850	Accept
5	0.916419	0.027995	11	4.109299	Accept
4	0.913174	0.028684	13	3.814745	Accept
3	0.918484	0.022981	17	5.161669	Accept
2	0.941109	0.017053	26	9.253900	Accept
1	0.948305	0.014383	50	11.837982	Accept

Table 4-4 - Periodic Review, 85% Service level

In each of the tables the third column reflects the computed reorder points (ROP) for the target service level at the given demand inter-arrival. It is necessary to round up in all instances to ensure that service will meet or exceed the target. For those instances when demand is less frequent the reorder point remains the same for several demand inter-arrival patterns. For example, looking in Table 4-4 we see that the ROP for 19 through 15 is 4. Note that this results in generally higher service levels for 19, with the service level decreasing as the customer demands increase. At 14 the ROP increases to 5, and we see the achieved service level increase as well. This saw-tooth effect is seen in Figure 4–1 and is reflected consistently throughout. Again, this behavior is expected given the need to round up the reorder points.

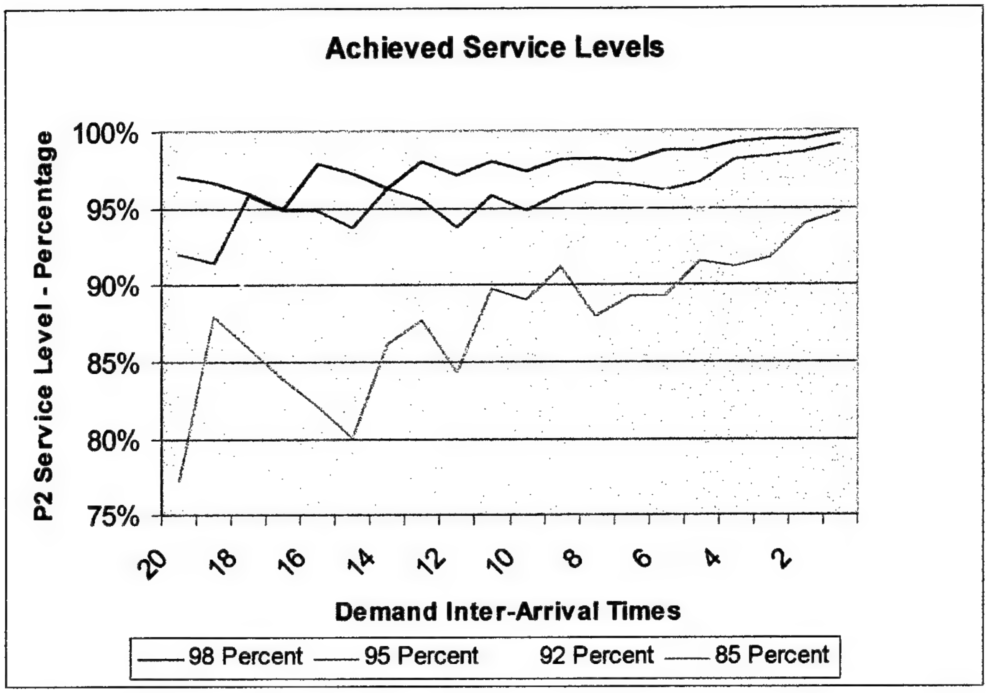

Figure 4–1 - Achieved P2 Service Levels

Hypothesis 1A$_c$ - Continuous Review Policy

As with the periodic review policy, the results of each of the runs was tested using a one tailed t-test. Again the confidence level was set to an α=0.05. The test statistic was compared to a t-score of -1.70, again where we reject the null hypothesis if the test statistic was less than or equal to -1.70.

We see in the results in Table 4-5 that at the 98% service level most of the demonstrated service levels (11 out of 20) were significantly below the target service level of 98%. Additionally another 4 were below the target service level, with one exactly at the service level. This would lead to the conclusion that this model, at the 98% service level tends to under perform in comparison to the theoretical values. The values for those instances where the null hypotheses were rejected were quite close to the target

value. The t-test used has tighter statistical limits than other tests. These values, while statistically not equal to or greater than the target service level, are close that to the general practitioner the conclusion would most liely be that they are "close enough."

Demand Interarrival	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	96.79%	1.69%	2	-3.92	Reject
19	97.92%	1.33%	3	-0.33	Accept
18	98.00%	1.40%	3	-0.01	Accept
17	97.75%	1.37%	3	-1.00	Accept
16	97.40%	1.51%	3	-2.16	Reject
15	97.14%	1.59%	3	-2.96	Reject
14	97.85%	1.28%	4	-0.63	Accept
13	97.55%	1.27%	4	-1.92	Reject
12	96.96%	1.52%	4	-3.75	Reject
11	97.63%	1.49%	5	-1.35	Accept
10	97.03%	1.35%	5	-3.93	Reject
9	97.48%	1.47%	6	-1.92	Reject
8	96.61%	1.60%	6	-4.79	Reject
7	96.92%	1.27%	7	-4.65	Reject
6	97.55%	1.45%	9	-1.71	Reject
5	97.42%	1.16%	10	-2.71	Reject
4	98.27%	0.87%	13	1.67	Accept
3	98.92%	0.58%	18	8.66	Accept
2	99.56%	0.31%	28	28.00	Accept
1	99.99%	0.03%	59	403.92	Accept

Table 4-5 - Continuous Review, 98% Service Level

Table 4-6 presents a somewhat different story. The performance of the continuous review model at the 95% service level performs more in line with theoretical performance. Looking at the results from the simulation run at a target service level of 95% shows that only one value (demand inter-arrival at one every 14 days) is rejected at an α= 0.05. Additionally, only four runs (demand inter-arrivals at 15, 11, 9 and 5) were accepted with the actual average performance below the target.

Demand Interarrival	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	96.79%	1.69%	2	5.82	Accept
19	96.45%	1.87%	2	4.24	Accept
18	96.14%	1.82%	2	3.42	Accept
17	95.63%	1.93%	2	1.78	Accept
16	95.01%	2.28%	2	0.02	Accept
15	94.61%	2.34%	2	-0.90	Accept
14	93.88%	2.14%	2	-2.88	Reject
13	95.67%	1.40%	3	2.59	Accept
12	95.35%	1.67%	3	1.14	Accept
11	94.55%	1.81%	3	-1.38	Accept
10	95.73%	1.41%	4	2.85	Accept
9	94.56%	1.61%	4	-1.50	Accept
8	95.37%	1.52%	5	1.32	Accept
7	95.55%	1.63%	6	1.84	Accept
6	95.11%	1.48%	7	0.41	Accept
5	94.62%	1.77%	8	-1.18	Accept
4	96.58%	1.29%	11	6.72	Accept
3	97.31%	1.03%	15	12.36	Accept
2	98.35%	0.76%	23	24.17	Accept
1	99.85%	0.18%	51	144.20	Accept

Table 4-6 - Continuous Review, 95% Service Level

Further, we see that in the runs conducted at the 92% service level (see Table 4-7) not a single run is rejected when we apply the one-tail t-test. In fact, all runs perform above the target service level (and some considerably better than the target service level.) Additionally, Table 4-8 reflects similar results, failing to reject the null hypothesis in every instance. Again, we see a significant increase in service levels above the target service levels as the demands become more frequent.

Demand Interarrival	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	93.71%	2.62%	1	3.57	Accept
19	93.43%	2.68%	1	2.93	Accept
18	92.94%	2.65%	1	1.94	Accept
17	92.30%	2.55%	1	0.65	Accept
16	95.01%	2.28%	2	7.22	Accept
15	94.61%	2.34%	2	6.12	Accept
14	93.88%	2.14%	2	4.81	Accept
13	93.01%	2.05%	2	2.71	Accept
12	92.10%	2.15%	2	0.24	Accept
11	94.04%	1.80%	3	6.20	Accept
10	93.28%	1.87%	3	3.75	Accept
9	92.13%	1.76%	3	0.42	Accept
8	93.31%	1.65%	4	4.35	Accept
7	93.70%	1.71%	5	5.42	Accept
6	93.49%	1.64%	6	4.96	Accept
5	92.77%	2.01%	7	2.09	Accept
4	93.27%	1.55%	9	4.48	Accept
3	95.35%	1.40%	13	13.12	Accept
2	97.24%	0.99%	21	28.95	Accept
1	99.54%	0.35%	46	119.36	Accept

Table 4-7 - Continuous Review, 92% Service Level

Demand Interarrival	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	0.883981	0.032804	0	5.67	Accept
19	0.879035	0.033579	0	4.74	Accept
18	0.873562	0.032461	0	3.98	Accept
17	0.866449	0.031718	0	2.84	Accept
16	0.856845	0.032779	0	1.14	Accept
15	0.912036	0.029142	1	11.66	Accept
14	0.903267	0.028391	1	10.28	Accept
13	0.892092	0.02908	1	7.93	Accept
12	0.879664	0.030824	1	5.27	Accept
11	0.862621	0.031355	1	2.20	Accept
10	0.895571	0.027009	2	9.24	Accept
9	0.879473	0.029799	2	5.42	Accept
8	0.856373	0.030149	2	1.16	Accept
7	0.872842	0.021714	3	5.76	Accept
6	0.88199	0.019586	4	8.95	Accept
5	0.873641	0.026499	5	4.89	Accept
4	0.883599	0.019942	7	9.23	Accept
3	0.898794	0.021437	10	12.47	Accept
2	0.931455	0.017942	17	24.87	Accept
1	0.981125	0.008178	39	87.82	Accept

Table 4-8 - Continuous Review, 85% Service Level

The data is represented in Figure 4–2 showing the achieved service levels. The saw-tooth pattern is again evident due in large part to the rounding up of the reorder points. Also note the continuous review policy seems more stable than the periodic review across the full range of demand patterns, while exhibiting the large increases in achieved service levels are demands approach one per day.

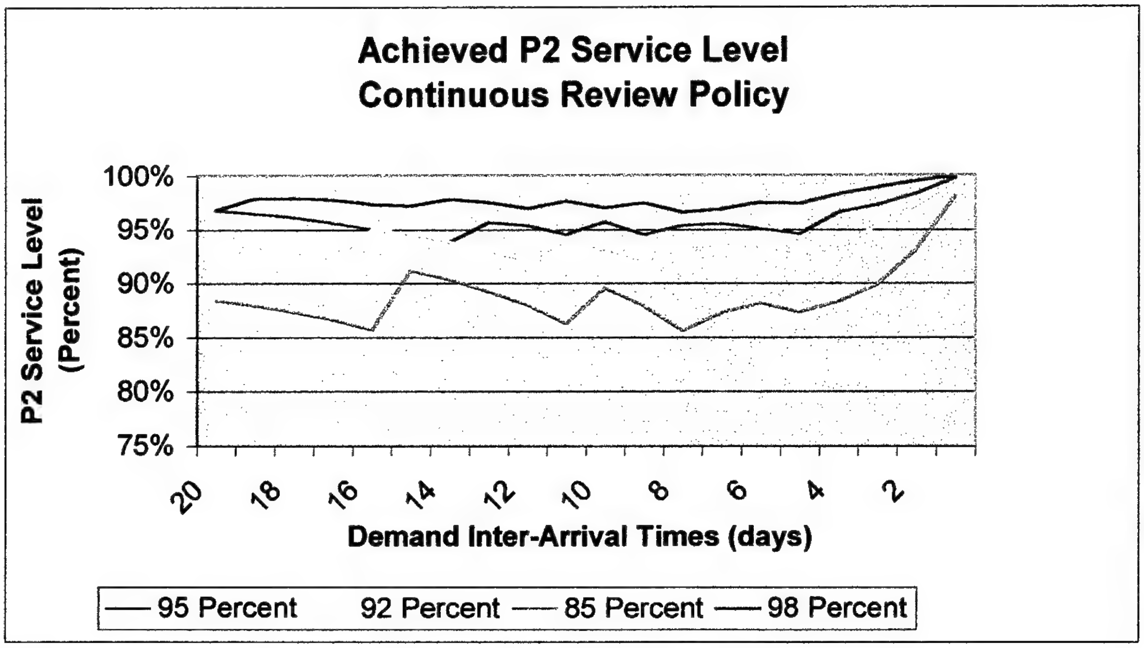

Figure 4–2 - Continuous Review Achieved P2 Service Levels

Hypothesis 1A$_i$ - Instantaneous Reorder Policy

While the other two policies generally met or exceeded the target service levels, the (s-1,S) instantaneous reordering policy met or exceeded the target levels in every instance. While there are no significant findings, the tables are included below for review. Table 4-9 shows the performance at the 98 percent service level. Note that while we fail to reject the null hypotheses for each run series, there are again instances where

the achieved performance levels are below the target levels, however the difference was not statistically significant.

Demand Arrivals	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	97.96%	1.17%	3	-0.063494	Accept
19	97.52%	1.32%	3	-0.624423	Accept
18	97.09%	1.44%	3	-1.094298	Accept
17	96.42%	1.63%	3	-1.680877	Accept
16	99.12%	0.61%	4	3.162108	Accept
15	98.87%	0.72%	4	2.096683	Accept
14	98.53%	0.85%	4	1.074478	Accept
13	98.08%	0.94%	4	0.140480	Accept
12	97.54%	1.15%	4	-0.693481	Accept
11	98.93%	0.74%	5	2.174228	Accept
10	98.29%	1.00%	5	0.509767	Accept
9	97.22%	1.32%	5	-1.019342	Accept
8	98.56%	0.87%	6	1.125381	Accept
7	97.27%	1.17%	6	-1.080681	Accept
6	97.85%	1.07%	7	-0.245043	Accept
5	97.90%	1.05%	8	-0.157632	Accept
4	98.55%	0.76%	10	1.252652	Accept
3	97.80%	0.99%	12	-0.351292	Accept
2	98.47%	0.76%	17	1.086120	Accept
1	98.46%	0.72%	30	1.114942	Accept

Table 4-9 - Instantaneous Reorder Policy, 98 Percent

In Table 4-10 we again accept (or, fail to reject) the null hypothesis. That is, this model, at all levels tested, demonstrated within statistical limits, that it meets or exceeds the target service level of 95 percent. Again, there are some instances where the actual performance measured was below the targets. These instances were at the break point between the reorder points, where the actual reorder point was closest to the number used. One can see this for instance in the case of demands arriving on average at one every 14 periods. In this case the reorder point is set at 3, when the next level of demands, one every 13 days, has the reorder point increasing to 4. This is just the low

end representation of the saw-tooth effect mentioned before. Again, while the demonstrated value is less than the target, the difference is not statistically significant.

Demand Arrivals	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	97.90%	1.20%	3	4.188568	Accept
19	97.44%	1.35%	3	3.136630	Accept
18	97.06%	1.44%	3	2.482527	Accept
17	96.34%	1.65%	3	1.401269	Accept
16	95.89%	1.76%	3	0.872905	Accept
15	95.15%	2.29%	3	0.110088	Accept
14	94.35%	2.50%	3	-0.451098	Accept
13	98.06%	0.95%	4	5.582720	Accept
12	97.50%	1.18%	4	3.682145	Accept
11	96.43%	1.43%	4	1.734271	Accept
10	94.87%	1.82%	4	-0.126364	Accept
9	97.22%	1.32%	5	2.904623	Accept
8	95.82%	1.75%	5	0.809803	Accept
7	97.26%	1.17%	6	3.344080	Accept
6	94.43%	1.79%	6	-0.550568	Accept
5	94.91%	1.72%	7	-0.093194	Accept
4	96.56%	1.18%	9	2.291603	Accept
3	95.64%	1.38%	11	0.798922	Accept
2	97.16%	1.06%	16	3.531936	Accept
1	96.32%	1.15%	28	2.000434	Accept

Table 4-10 - Instantaneous Reorder Policy, 95 Percent

Table 4-11 and Table 4-12 both show the results for the model with the target service level set to 92 and 85 percent respectively. Not only do we fail to reject the null hypothesis in applying the t-test, but in these cases, at no time does the demonstrated value drop below the target value. The test statistic is showing large positive numbers, however these are acceptable given the test under consideration, that is, that the demonstrated value (mean service level) is at least equal to 92 percent.

Demand Arrivals	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	97.77%	1.22%	3	8.174154	Accept
19	97.26%	1.47%	3	6.212686	Accept
18	96.92%	1.56%	3	5.466976	Accept
17	96.18%	1.70%	3	4.254653	Accept
16	95.62%	1.97%	3	3.175561	Accept
15	94.93%	2.37%	3	2.141741	Accept
14	94.23%	2.51%	3	1.537173	Accept
13	93.04%	2.98%	3	0.602525	Accept
12	97.34%	1.38%	4	6.708225	Accept
11	96.34%	1.49%	4	5.051620	Accept
10	94.76%	1.90%	4	2.514721	Accept
9	92.63%	2.44%	4	0.449532	Accept
8	95.78%	1.79%	5	3.662122	Accept
7	92.76%	2.20%	5	0.598134	Accept
6	94.39%	1.81%	6	2.283146	Accept
5	94.87%	1.73%	7	2.877332	Accept
4	92.92%	1.90%	8	0.837811	Accept
3	95.63%	1.38%	11	4.546595	Accept
2	94.99%	1.33%	15	3.889917	Accept
1	94.48%	1.46%	27	2.950099	Accept

Table 4-11 - Instantaneous Reorder Policy, 92 Percent

Demand Arrivals	Percent	Std Dev	ROP	Test Statistic	One Tailed t-Test
20	91.11%	3.42%	2	3.095242	Accept
19	89.88%	3.77%	2	2.242648	Accept
18	88.70%	3.65%	2	1.755447	Accept
17	87.19%	3.78%	2	1.002045	Accept
16	85.49%	3.93%	2	0.215829	Accept
15	94.01%	2.77%	3	5.631639	Accept
14	93.07%	3.09%	3	4.528831	Accept
13	92.07%	3.38%	3	3.628175	Accept
12	90.14%	3.72%	3	2.390970	Accept
11	87.90%	3.64%	3	1.379596	Accept
10	94.08%	2.29%	4	6.864737	Accept
9	91.92%	2.86%	4	4.196119	Accept
8	88.59%	3.28%	4	1.895730	Accept
7	92.33%	2.48%	5	5.116634	Accept
6	87.19%	2.92%	5	1.296252	Accept
5	88.53%	2.59%	6	2.361840	Accept
4	92.69%	2.08%	8	6.417029	Accept
3	91.58%	1.97%	10	5.783204	Accept
2	91.47%	1.57%	14	7.149062	Accept
1	92.04%	1.67%	26	7.283177	Accept

Table 4-12 - Instantaneous Reorder Policy, 85 Percent

Finally, the performance of the model is summarized on the chart show at Figure 4–3. Again, the saw-tooth effect is prominent. The instantaneous reorder policy does not seem to exhibit the same "ramping up" effect seen in the previous two models. While the model does exhibit performance greater than the target, there is no marked increase as demand approaches one per day.

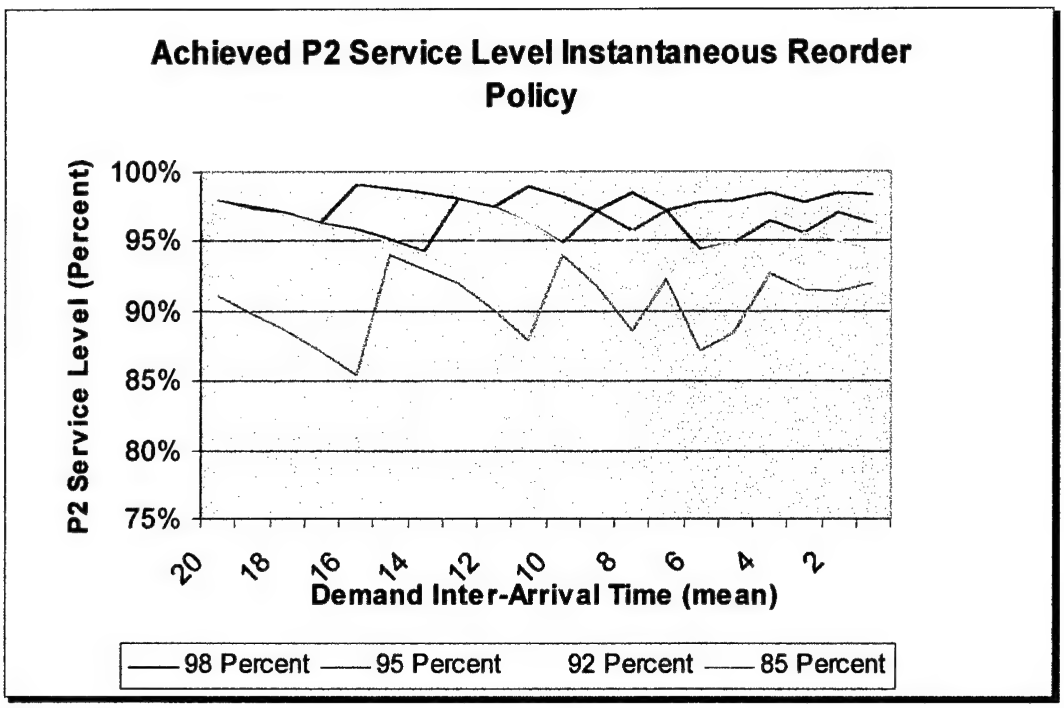

Figure 4–3 - Instantaneous Review Policy Achieved P2 Service Levels

In summary, we can see from the testing of each of these policies that when run as independent models the policies generally perform at or above the target service level. Additionally, the saw-tooth behavior seen is resultant from the necessity to round up to ensure service levels are equal to, or greater than, the target service level. This leads us to conclude that the model, and its components, are generally behaving in a fashion consistent with theory.

Hypothesis 1B - Policies Compared to Theoretical in Full Model

The first part of the first research question dealt with the verification and validation issue of assessing the performance of the model, assessing whether it performs as expected, and allowing for the establishing of a baseline of performance. The second part of the first research question addresses whether the ordering policies in the model perform as expected. This portion of the research question is presented by target service level, and presents each of the reordering policies' performance for that target service level. This is because these runs are the results of the full interactive model, and this means of presenting the data allows that the reader to get a feel for the full model's performance. The results for each of the sub-hypotheses (Hypothesis $1B_p$, Hypothesis $1B_c$, and Hypothesis $1B_i$) are presented as the service level performance is discussed.

The results of the fully interactive model run at the 98 percent service level are reflected in Table 4-13. Again, the one-tail t-test is employed comparing each achieved mean against the target service level of 98 percent. If the t* value achieved is greater than the test statistic of -1.70 (at alpha=0.05) then we reject the null hypothesis. This is seen in the first set of data for the periodic review. In that instance, the mean achieved is 97.29%, with a standard deviation of 2.01. Using the equation listed at Equation 4-12 we find:

$$t^* = \frac{97.29 - 98}{\frac{2.01}{\sqrt{30}}} = -1.94$$

Equation 4-14 - t-Test, Periodic Review, in Full Model

Thus, since the t* is less than the test statistic of -1.70, we would reject the null hypothesis that the actual mean is 98% or greater.

We see here then that the null hypothesis for periodic review policy (Hypothesis $1B_p$) is rejected when the demand inter-arrival time is 20, 19, 18, 17, 15, 14, 12 and 10. The null hypothesis is not rejected for the remaining 13 runs. For the continuous review policy the null (Hypothesis $1B_c$) is rejected for four runs, failing to reject sixteen, while for the instantaneous reorder policy (Hypothesis $1B_i$) six runs (of thirty replications) result in the rejection of the null.

Target Service Level	98%		Tested at:	1.70	Target Service Level	98% Tested at:		1.70	Target Service Level	98% at:	Tested	1.70
	Periodic Review				Continuous Review				Instantaneous Review			
Demand Arrival	Percent	Std Dev	t-Score	Test	Percent	Std Dev	t-Score	Test	Percent	Std Dev	t-Score	Test
	97.29%	2.01%	-1.94	Reject	97.68%	1.42%	-1.25	Accept	97.96%	1.27%	-0.18	Accept
19	96.96%	1.82%	-3.14	Reject	98.74%	1.05%	3.87	Accept	97.31%	1.32%	-2.88	Reject
18	96.11%	2.53%	-4.10	Reject	98.04%	1.30%	0.16	Accept	97.14%	1.39%	-3.38	Reject
17	95.42%	2.15%	-6.58	Reject	97.87%	1.20%	-0.61	Accept	96.49%	1.62%	-5.13	Reject
16	97.69%	1.77%	-0.97	Accept	97.95%	1.36%	-0.21	Accept	99.00%	0.65%	8.50	Accept
15	97.16%	1.66%	-2.76	Reject	97.61%	1.48%	-1.43	Accept	98.78%	1.21%	3.54	Accept
14	96.73%	1.58%	-4.39	Reject	98.25%	1.05%	1.32	Accept	98.40%	0.95%	2.30	Accept
13	98.03%	1.47%	0.11	Accept	98.03%	1.36%	0.13	Accept	98.09%	1.14%	0.42	Accept
12	97.21%	1.14%	-3.80	Reject	97.30%	1.33%	-2.91	Reject	97.40%	1.40%	-2.33	Reject
11	98.28%	1.23%	1.24	Accept	98.02%	1.36%	0.08	Accept	99.08%	0.65%	9.15	Accept
10	97.06%	1.67%	-3.07	Reject	97.54%	1.29%	-1.95	Reject	98.66%	0.83%	4.35	Accept
9	97.80%	1.45%	-0.75	Accept	97.91%	1.36%	-0.37	Accept	97.49%	1.38%	-2.01	Reject
8	98.02%	1.27%	0.09	Accept	97.49%	1.35%	-2.05	Reject	98.53%	1.10%	2.64	Accept
7	97.95%	1.35%	-0.21	Accept	97.02%	1.62%	-3.32	Reject	97.20%	1.17%	-3.76	Reject
6	99.00%	0.88%	6.24	Accept	98.04%	1.25%	0.17	Accept	98.02%	0.95%	0.11	Accept
5	98.86%	0.98%	4.76	Accept	97.81%	1.03%	-1.04	Accept	97.75%	1.23%	-1.13	Accept
4	99.11%	0.71%	8.50	Accept	98.25%	0.90%	1.55	Accept	98.52%	0.79%	3.59	Accept
3	99.50%	0.36%	22.81	Accept	98.89%	0.74%	6.62	Accept	98.04%	0.90%	0.26	Accept
2	99.68%	0.34%	26.74	Accept	99.64%	0.31%	29.21	Accept	98.57%	0.73%	4.31	Accept
1	99.85%	0.17%	60.75	Accept	99.99%	0.03%	400.05	Accept	98.77%	0.61%	6.90	Accept

Table 4-13 - Full Model Results, 98 Percent Service

The chart contained in Figure 4–4 below shows the performance of each of the policies for each of the demand inter-arrival times. Note the saw-tooth effect again resulting from the reorder point policy. The chart also graphically presents the improvement in performance of the periodic review policy as the frequency of demands

increases in relation to re-supply lead-time. Additionally, the graph shows the relative consistency of the other two policies over time, with all three policies showing service levels increasing to nearly 100 percent as the demands in the model approaches one each day. Also of interest are the differences in performance between policies. This will be revisited in Research Questions Three and Four.

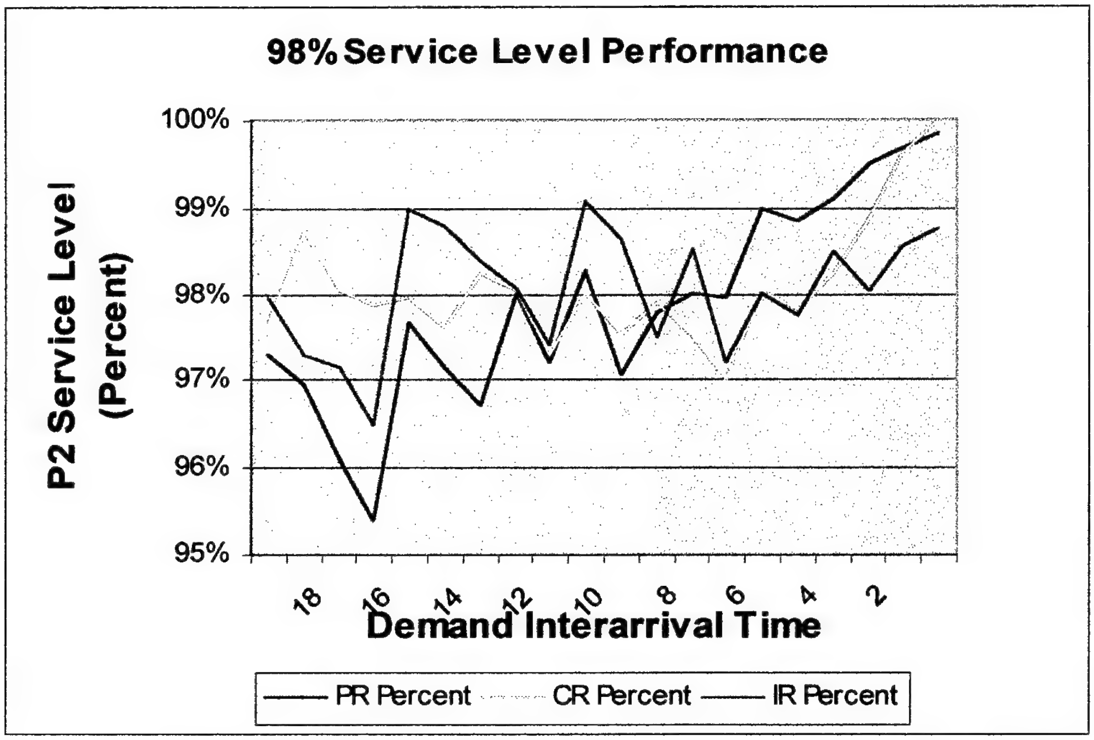

Figure 4–4 - Achieved P2 Service Level, all Models 98 Percent

For the model run at 95 percent target service level, we find in Figure 4–4 that we fail to reject the null hypothesis (Hypothesis $1B_c$) for every single run under the Continuous Review Policy. We reject the null hypothesis (Hypothesis $1B_p$) for four of the runs for the Periodic Review Policy under consideration, when demand inter-arrival times are 20,19,16, 15, and 12. For or all practical purposes the null hypothesis (Hypothesis $1B_p$) is accepted for the remaining 16 runs. Finally, only two runs (demands

of -1.70 for the Instantaneous Reorder Policy, with the null hypothesis for the remaining 18 runs being accepted.

Target Service Level	95%		Tested at:	1.70	Target Service Level	95% Tested at:		1.70	Target Service Level	95% Tested at:		1.70
	Periodic Review				Continuous Review				Instantaneous Review			
Demand Arrival	Percent	Std Dev	t-Score	Test	Percent	Std Dev	t-Score	Test	Percent	Std Dev	t-Score	Test
	92.57%	2.96%	-4.49	Reject	97.66%	1.44%	10.10	Accept	97.93%	1.29%	12.44	Accept
19	91.90%	2.79%	-6.09	Reject	97.27%	1.73%	7.20	Accept	97.35%	1.35%	9.57	Accept
18	96.04%	2.42%	2.34	Accept	95.79%	2.36%	1.84	Accept	97.11%	1.30%	8.90	Accept
17	95.39%	2.15%	1.00	Accept	96.30%	1.94%	3.67	Accept	96.46%	1.56%	5.13	Accept
16	94.14%	2.34%	-2.01	Reject	96.59%	1.42%	6.13	Accept	96.01%	1.55%	3.58	Accept
15	93.29%	2.60%	-3.59	Reject	96.03%	1.61%	3.48	Accept	94.89%	2.16%	-0.29	Accept
14	96.19%	2.59%	2.51	Accept	94.81%	2.00%	-0.52	Accept	94.19%	2.00%	-2.21	Reject
13	95.75%	2.14%	1.93	Accept	96.70%	1.32%	7.07	Accept	98.24%	1.25%	14.20	Accept
12	93.98%	1.95%	-2.86	Reject	96.24%	1.50%	4.51	Accept	97.32%	1.46%	8.69	Accept
11	95.82%	1.64%	2.73	Accept	95.30%	1.74%	0.94	Accept	96.45%	1.43%	5.55	Accept
10	94.83%	1.85%	-0.50	Accept	96.25%	1.84%	3.72	Accept	95.55%	1.67%	1.81	Accept
9	95.87%	2.02%	2.35	Accept	95.01%	2.26%	0.03	Accept	97.54%	1.37%	10.12	Accept
8	96.27%	1.90%	3.65	Accept	95.78%	1.48%	2.90	Accept	95.58%	1.74%	1.81	Accept
7	96.48%	1.49%	5.44	Accept	95.62%	1.85%	1.85	Accept	97.11%	1.16%	9.98	Accept
6	96.53%	1.63%	5.16	Accept	95.74%	1.59%	2.54	Accept	94.38%	1.73%	-1.97	Reject
5	96.76%	1.27%	7.61	Accept	94.57%	2.04%	-1.15	Accept	94.65%	1.97%	-0.98	Accept
4	98.32%	0.96%	18.91	Accept	96.40%	2.15%	3.56	Accept	96.62%	1.17%	7.55	Accept
3	98.53%	0.81%	23.89	Accept	97.55%	0.94%	14.95	Accept	95.88%	1.24%	3.89	Accept
2	98.68%	0.65%	30.93	Accept	98.63%	0.78%	25.53	Accept	97.31%	0.93%	13.58	Accept
1	99.21%	0.45%	51.17	Accept	99.91%	0.13%	209.80	Accept	96.69%	0.96%	9.58	Accept

Table 4-14 - Results Full Model, 95 Percent Service

Once again, we see reflected in the chart in Figure 4–5 the achieved service levels for each of the three policies when run with a target of 95 percent. The periodic review policy shows the characteristic of an improving trend of upward service levels as the demand becomes more frequent. Additionally, it appears that the Continuous Review Policy is again more stable, while the Instantaneous Reorder Policy shows greater volatility/swings in service levels from demand to demand.

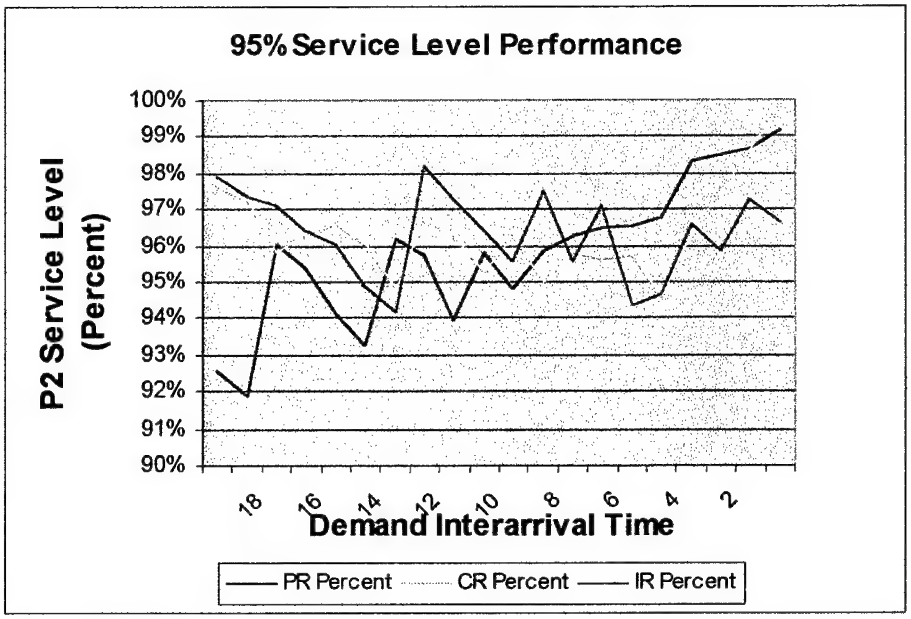

Figure 4–5 - Achieved Service Levels, All Policies, 95% Service Level

As the target service levels decrease to 92 percent, we see and fewer rejections of the null hypotheses. Table 4-1 shows that the null hypothesis is rejected for the periodic review policy (Hypothesis $1B_p$) in only three instances, when demand arrives once every 18 days, 17 days, and 13 days. The null hypotheses for each of the other two policies (Hypothesis $1B_c$ and Hypothesis $1B_i$) are in effect accepted concluding that, with a 0.05 significance level, the mean for these policies at the tested demand rates and lead times is equal to or greater than the target service level of 92 percent.

Target Service Level	92%		Tested at:	98.00%	Target Service Level	92% Tested at:		98.00%	Target Service Level	92% Tested at:		98.00%
	Periodic Review				Continuous Review				Instantaneous Review			
Demand Arrival	Percent	Std Dev	Z-Score	Test	Percent	Std Dev	Z-Score	Test	Percent	Std Dev	Z-Score	Test
	92.40%	2.91%	0.75	Accept	94.89%	2.43%	6.53	Accept	97.79%	1.44%	21.96	Accept
19	91.65%	2.53%	-0.75	Accept	94.81%	2.10%	7.32	Accept	97.39%	1.42%	20.77	Accept
18	90.45%	3.05%	-2.79	Reject	93.74%	2.43%	3.93	Accept	97.09%	1.20%	23.20	Accept
17	89.17%	3.01%	-5.14	Reject	93.43%	2.56%	3.07	Accept	96.48%	1.65%	14.89	Accept
16	94.13%	2.36%	4.95	Accept	96.57%	1.43%	17.52	Accept	95.93%	1.68%	12.78	Accept
15	93.28%	2.61%	2.70	Accept	96.03%	1.61%	13.67	Accept	94.83%	2.14%	7.24	Accept
14	91.79%	3.42%	-0.33	Accept	94.79%	1.99%	7.69	Accept	94.17%	2.00%	5.93	Accept
13	90.50%	3.08%	-2.67	Reject	94.33%	1.85%	6.91	Accept	93.05%	2.57%	2.24	Accept
12	93.87%	2.32%	4.42	Accept	93.85%	2.26%	4.48	Accept	97.44%	1.48%	20.15	Accept
11	91.98%	2.37%	-0.05	Accept	95.30%	1.74%	10.42	Accept	96.45%	1.43%	17.02	Accept
10	94.73%	1.88%	7.94	Accept	94.28%	1.80%	6.91	Accept	95.50%	1.61%	11.87	Accept
9	92.14%	2.28%	0.34	Accept	93.06%	2.41%	2.41	Accept	92.79%	2.31%	1.87	Accept
8	93.25%	2.40%	2.85	Accept	93.76%	2.19%	4.41	Accept	95.71%	1.61%	12.61	Accept
7	94.59%	2.11%	6.73	Accept	94.04%	1.88%	5.94	Accept	92.58%	2.14%	1.48	Accept
6	96.44%	1.60%	15.17	Accept	93.91%	1.41%	7.41	Accept	94.50%	1.62%	8.45	Accept
5	94.83%	1.69%	9.20	Accept	93.65%	1.88%	4.81	Accept	94.83%	1.90%	8.17	Accept
4	95.80%	1.59%	13.11	Accept	93.50%	2.10%	3.91	Accept	92.91%	1.78%	2.82	Accept
3	96.91%	1.43%	18.76	Accept	95.51%	1.50%	12.85	Accept	95.80%	1.22%	17.10	Accept
2	97.05%	1.02%	27.10	Accept	97.52%	0.92%	32.98	Accept	95.32%	1.32%	13.73	Accept
1	97.98%	0.99%	32.94	Accept	99.53%	0.42%	97.44	Accept	95.00%	1.21%	13.58	Accept

Table 4-15 - Achieved Service Levels, All Policies, 92% Service Levels

As noted in the previous two figures, Figure 4–1 shows the performance of each of the policies for each of the demand arrival patterns tested. Again, the performance of the Periodic Review Policy improves as the demand rate increases, thus the more frequent the average demands, the better performance would be expected from the periodic policy, over the range tested.

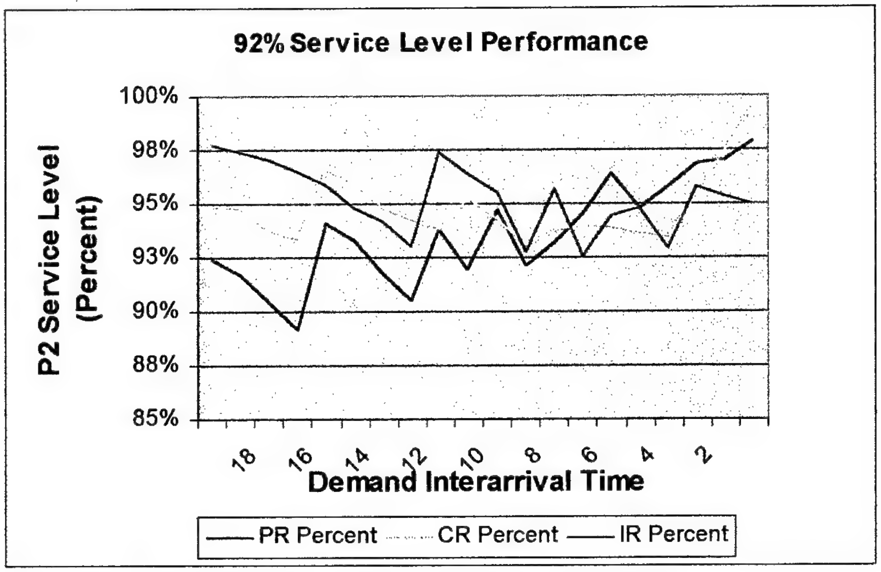

Figure 4-6 - Achieved Service Levels, All Policies, 92% Service

Finally, the achieved service levels of the models at the 85 percent target service level is tested against the hypotheses that they perform at a level equal to or greater than the target service level. Note on Table 4-16 that the periodic review policy has the only instance of rejecting of the null hypothesis for this target service level. All other policies are assumed to meet the null hypothesis.

Target Service Level	85%		Tested at:	98.00%	Target Service Level	85% Tested at:		98.00%	Target Service Level	85% Tested at:		98.00%
	Periodic Review				Continuous Review				Instantaneous Review			
Demand Arrival	Percent	Std Dev	Z-Score	Test	Percent	Std Dev	Z-Score	Test	Percent	Std Dev	Z-Score	Test
	81.56%	3.51%	-5.37	Reject	88.68%	3.09%	6.52	Accept	90.80%	3.01%	10.55	Accept
19	90.85%	2.89%	11.10	Accept	88.58%	2.78%	7.04	Accept	90.29%	3.43%	8.45	Accept
18	90.79%	2.28%	13.89	Accept	87.40%	3.27%	4.02	Accept	88.99%	2.49%	8.78	Accept
17	89.20%	2.60%	8.86	Accept	87.90%	2.41%	6.57	Accept	87.65%	3.19%	4.54	Accept
16	87.44%	3.34%	4.00	Accept	87.33%	3.02%	4.23	Accept	85.77%	3.60%	1.16	Accept
15	85.22%	3.63%	0.32	Accept	91.93%	3.05%	12.46	Accept	94.56%	2.27%	23.06	Accept
14	91.67%	3.32%	10.99	Accept	92.14%	2.27%	17.27	Accept	93.94%	1.94%	25.18	Accept
13	90.32%	3.19%	9.12	Accept	91.00%	2.35%	13.96	Accept	92.89%	2.58%	16.77	Accept
12	88.64%	2.52%	7.90	Accept	89.61%	2.95%	8.58	Accept	91.80%	2.95%	12.64	Accept
11	91.76%	2.26%	16.35	Accept	88.04%	2.70%	6.17	Accept	89.08%	3.12%	7.16	Accept
10	89.93%	2.76%	9.80	Accept	90.19%	2.18%	13.07	Accept	95.33%	1.72%	32.87	Accept
9	92.10%	2.31%	16.85	Accept	89.52%	3.05%	8.10	Accept	92.85%	2.19%	19.66	Accept
8	88.67%	2.51%	8.02	Accept	86.98%	3.03%	3.57	Accept	89.29%	3.14%	7.48	Accept
7	90.66%	3.01%	10.29	Accept	88.81%	2.45%	8.51	Accept	92.87%	2.13%	20.23	Accept
6	89.91%	2.62%	10.28	Accept	87.90%	3.25%	4.90	Accept	88.00%	2.82%	5.83	Accept
5	92.49%	2.54%	16.15	Accept	88.33%	2.83%	6.46	Accept	88.55%	3.15%	6.17	Accept
4	90.95%	2.25%	14.50	Accept	89.34%	2.10%	11.29	Accept	92.96%	1.87%	23.30	Accept
3	91.81%	2.06%	18.15	Accept	91.16%	2.43%	13.88	Accept	92.17%	1.74%	22.55	Accept
2	94.79%	1.89%	28.38	Accept	93.26%	1.88%	24.08	Accept	91.71%	1.77%	20.75	Accept
1	94.35%	1.39%	36.79	Accept	98.44%	0.86%	85.49	Accept	92.35%	1.65%	24.44	Accept

Table 4-16 - Achieved Service Levels, All Policies, 85 Percent

The Chart at Figure 4–7 is included for completeness. Note the similar performance of each policy under this service policy and under each of the other three service policies.

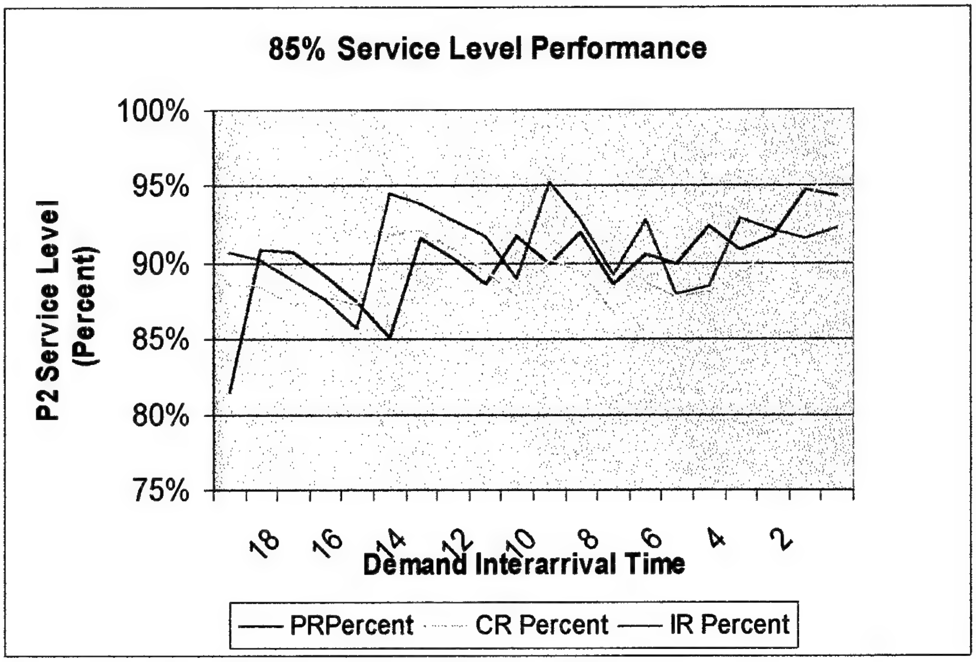

Figure 4–7 - Achieved Service Levels, All Policies, 85 Percent

Given these results we can conclude that overall each of the policies perform in line with theoretical expectations in the full interactive model. There are instances with specific customer demand arrivals when we reject the null hypothesis, however these are relatively few. These are typically at the cusp where the reorder point is changing, and we can expect in these instances that any deviation from the normal assumption would result in other than expected performance.

Research Question Two - Independent and Full Model Comparison Between Policies

The second hypothesis seeks to determine if there is a statistically significant difference between the performance of an ordering policy when it is run without competing policies, and when it is used in an environment where it is interacting and perhaps competing with other policies in use. To test this hypothesis a standard test of hypothesis was conducted. For this analysis both a two tailed and a one tailed test were conducted. The results of the two tailed tests are presented first, testing whether the means achieved in both tests can be considered "equal" with any statistical significance. The one-tailed tests results are used for those instances where the null hypothesis was rejected, to determine if the performance of the reordering policy was worse in the full interactive model than in the independent model.

To conduct this test, the z-score is used as the test statistic. The z-score is computed by:

$$z^* = \frac{\bar{x} - \bar{y} - 0}{\sqrt{\frac{s_x^2}{n} + \frac{s_y^2}{m}}}$$

Equation 4-15 - Test for Difference of Two Means (Large Sample)

The test statistic used is $z_{\alpha/2}$ for the two tailed test, and z_α for the one tailed test. Each of the tests were conducted with an $\alpha=0.05$ for a 95% significance. For these tests then, the two tailed test has as the test statistic $z=1.96$, and for the one tailed test $z=1.64$. We reject the null hypothesis for the two tailed test when the absolute value of z^* is greater than 1.96. For the one tailed test, we are testing the null hypothesis that the two

means are equal with the alternative hypothesis that the independent run performed better than the full interactive model. To test this, the null hypothesis is rejected when the z* score is greater than 1.64.

In the two tailed tests, all but thirteen of the null hypotheses were accepted. Only those 13 will be presented here. The complete data set is contained in Appendix F. Additionally, the 13 that were rejected were assessed using the one-tailed test.

Four hypotheses were rejected for the continuous review model. Two were rejected when the target service level was 95 percent (customer demands every sixteen and thirteen days--see Table 4-17).

Continuous Review						
	Full Run		Independent Run			Test of
Demands	Percent	Std Dev	Percent	Std Dev	z-Score	Differences
16	96.59%	1.42%	95.01%	2.28%	-2.34	Reject
13	96.70%	1.32%	95.67%	1.40%	-2.08	Reject

Table 4-17 - Continuous Review 95 Percent Service Level

The results were computed using the above equation such that for the first instance, with mean demand inter-arrivals equal to sixteen:

$$z^* = \frac{95.01 - 96.59 - 0}{\sqrt{\dfrac{2.28^2}{30} + \dfrac{1.42^2}{30}}} = -2.34$$

Equation 4-16

The z* values were computed similarly for each of the values of the test.

Two were rejected with the target service level at 92 percent (customer demands arriving on average every sixteen and twelve days).

Continuous Review						
	Full Run		Independent Run			Test of
Demands	Percent	Std Dev	Percent	Std Dev	z-Score	Differences
16	96.57%	1.43%	95.01%	2.28%	-2.30	Reject
12	93.85%	2.26%	92.10%	2.15%	-2.18	Reject

Table 4-18 - Continuous Review 92 Percent Service Level

The remaining nine hypotheses that were rejected were all for the periodic review model when the target service level was 85 percent (see Table 4-19.) The null hypothesis was rejected for those tests of hypothesis when the average demand inter-arrivals was from twenty to twelve. That is, the absolute value of the z-score was greater than the test statistic of z=1.64, leading to the conclusion that for these nine hypotheses the means are different when the policy operates independently from when it is interacting with other policies. There is apparently a variation in performance when demands are slow for the periodic review policy when run independently and when it is run in the full model. The application of the one-tailed test will provide insight into the reasons for the performance variation.

Periodic Review						
	Full Run		Independent Run			Test of
Demands	Percent	Std Dev	Percent	Std Dev	z-Score	Differences
20	81.56%	3.51%	77.34%	5.74%	-2.50	Reject
19	90.85%	2.89%	88.03%	4.56%	-2.07	Reject
18	90.79%	2.28%	85.87%	5.77%	-3.35	Reject
17	89.20%	2.60%	83.83%	4.59%	-4.09	Reject
16	87.44%	3.34%	82.22%	4.32%	-3.73	Reject
15	85.22%	3.63%	80.11%	5.40%	-3.09	Reject
14	91.67%	3.32%	86.11%	4.59%	-3.85	Reject
13	90.32%	3.19%	87.72%	3.15%	-2.24	Reject
12	88.64%	2.52%	84.33%	3.71%	-3.79	Reject

Table 4-19 - Periodic Review 85 Percent Service Level

The one tailed test was applied to each of these, again, with the critical region being defined as rejecting the null hypothesis if the computed z* value is greater than 1.64. No additional computations are required since the z* values have already been computed. It is obvious from the above three tables that none of these runs are above z*=1.64, and thus we conclude that the independent runs in these cases did not have a higher service level than the full interactive run. In fact, we can then conclude that for the performance of these models, the ordering policies in these instances performed better in the interactive model than when no interactions between policies are present (in the independent model.) This could be due to the leveling effect of demands introduced by the instantaneous reordering policy. In other words, when the periodic review policy and continuous review policies are operating independently they are presenting a lumpy demand pattern to the warehouse, and the introduction of the unit-sized demands from the instantaneous reordering policy may be dampening the effect of that lumpy demand.

Research Question Three - Test of Equality Between Means

In this hypothesis, the question is whether the means of each of the reordering policies are equal when run in the full interactive model. That is, does the periodic review policy perform identically to the continuous review policy, and to the instantaneous reordering policy? To test this hypothesis a one way analysis of variance (ANOVA) test is used. The complete results of the ANOVA test are contained in Appendix E. For this test the null hypothesis is that each of the means are equal, while the alternative hypothesis is that at least one of the means is not equal. Given this test we

cannot determine which mean value is statistically different, or whether they are all different from each other. That question is addressed in Research Question Four.

The test statistic applied in this test is the F value, or the F-criteria. If the F score is greater than 3.101 then we reject the null hypothesis and conclude that at least one of the means is different. Alternatively, if the F-score is below 3.101 then we fail to reject the null hypothesis and can then generally conclude that the means are statistically equal.

Table 4-20 shows the results of the ANOVA test conducted for the mean values when the target service level is 98 percent. We see here that only four runs (demand inter-arrivals of 20, 13, 12, and 9) result in an F-score of less than 3.101, and therefore we conclude that for most of the runs, at least one of the means is different from the rest.

Service Policy 98 %		
Interarrival	F-Score	p-Value
20	1.33006	0.269785
19	13.08456	1.08E-05
18	8.411579	0.000457
17	15.63894	1.58E-06
16	8.121032	0.000584
15	9.80017	0.000145
14	17.02237	5.77E-07
13	0.018513	0.981661
12	0.1677	0.84588
11	7.287904	0.001185
10	11.75539	3.03E-05
9	0.709579	0.494675
8	5.19263	0.007407
7	3.7807	0.02664
6	8.765621	0.00034
5	9.917921	0.000132
4	8.782766	0.000335
3	32.65546	2.63E-11
2	47.91991	9.31E-15
1	98.3037	4.74E-23

Table 4-20 - F-Scores 98 Percent Service Level

The remaining F-Scores (shown at Table 4-21) present a similar picture. In these remaining tests most resulted in a rejection of the null hypothesis. From this then we can conclude that at least one of the three means is different, but not other conclusions can be drawn.

Service Policy 95 %			Service Policy 92 %			Service Policy 85 %		
	F-Score	p-Value		F-Score	p-Value		F-Score	p-Value
20	65.54417	4.35E-18	20	39.89098	5.08E-13	20	68.14222	1.56E-18
19	69.85468	8.06E-19	19	57.87273	1.04E-16	19	4.543485	0.013279
18	3.35791	0.039375	18	59.48499	5.23E-17	18	11.72395	3.1E-05
17	2.753327	0.069273	17	66.08359	3.51E-18	17	2.751233	0.069409
16	14.90795	2.71E-06	16	13.81642	6.15E-06	16	2.375231	0.098998
15	12.07155	2.36E-05	15	12.17775	2.17E-05	15	75.72202	8.97E-20
14	6.373149	0.002613	14	11.46429	3.81E-05	14	6.449963	0.002443
13	18.14528	2.59E-07	13	17.54157	3.98E-07	13	7.157305	0.001325
12	31.81182	4.27E-11	12	30.40238	9.72E-11	12	9.942913	0.000129
11	3.894868	0.023987	11	45.41112	3.12E-14	11	14.96532	2.6E-06
10	4.72119	0.011309	10	3.663026	0.02969	10	54.50586	4.52E-16
9	13.39753	8.47E-06	9	1.226035	0.298473	9	14.13994	4.82E-06
8	1.281425	0.282829	8	11.55783	3.54E-05	8	5.101534	0.008035
7	7.202886	0.001275	7	7.756686	0.000795	7	18.90788	1.52E-07
6	13.08758	1.07E-05	6	21.99199	1.86E-08	6	4.566655	0.013004
5	14.38967	3.99E-06	5	4.199749	0.018148	5	20.2064	6.2E-08
4	14.29893	4.27E-06	4	20.77989	4.2E-08	4	22.83323	1.07E-08
3	52.78419	9.76E-16	3	8.564456	0.000402	3	1.769357	0.17652
2	28.3233	3.36E-10	2	33.19403	1.94E-11	2	20.90991	3.84E-08
1	224.7594	4.29E-35	1	180.7137	1.05E-31	1	161.0966	5.63E-30

Table 4-21- F-Scores Service Levels 95, 92, and 85 Percent

In summary then, with only ten exceptions, we conclude that the policies perform differently from one another. This is significant in that, while other research has shown certain policies to be superior to others in terms of cost, this shows that for specific demand patterns real performance differences exist in achieved service levels, even when targeting the same theoretical target level of service. This is separate from any performance variations due to cost issues. Given this test then we are left with the

question as to which ones are different, and thus which policies perform better than the others.

Research Question Four - Performance Comparisons

As noted above, 70 of the tests of hypothesis for Research Question Three resulted in a finding that at least one of the means is different for those parameters. This research question seeks to determine which policies outperform the other policies.

The test applied to assess this question is the Newman-Kuels Method. This method applies the Honest Significant Difference test several times to determine which means are truly statistically different from the others, or whether each of the means is different. This test is only applicable when each group has the same sample size, which makes it appropriate in this case with a sample size of 30 for each group. The test statistic for this is:

$$D_s = Q_{score} * s_p * \sqrt{\frac{1}{n}}$$

Equation 4-17

where the Q Score is derived from a table given the total number of degrees of freedom as computed in the ANOVA for the measure of error between groups. For these tests two values of Q are of interest. When comparing all three groups the value of Q is 3.38 extrapolated. When comparing two groups the value of Q is 2.815. Each of these values assumes a significance of α=0.05. The value sp is the mean square of the error from the ANOVA analysis. The value n is the number of samples in one group. To test the hypothesis, we order the means of all three groups, then subtract the value of the lowest mean from the highest value. We then compare that value to the value of Ds. The

null hypothesis (that the means under consideration are equal) is rejected if the computed value is greater than the value of Ds. The null hypothesis is not rejected if the value is less than or equal to Ds. If the null is not rejected then the test stops since the values between to maximum and minimum values cannot be larger than the extremes. If the null hypothesis is rejected then do the test again for the first two means, and then the last two.

The resulting values for the runs at the 98 percent target service level are shown in Table 4-1. This table (and the others that follow) reflects the test of the three in the left series of columns, the center series of columns reflects the test of pairs, with the first test being the highest value minus the mid-range value, and the second test being the mid-range value minus the the lowest value. The third group of columns reflects the odinal rankings of the policies.

For example, when the demands arrived every 19 days on average, the mean values are ranked from highest to lowest, with the Continuous Review Policy having the highest mean service level, and the Periodic Review Policy having the lowest. For the first test, the test statistic is 0.008834. Thus, if the value of the mean service level for the continous review policy minus the mean service level for the periodic review policy is greater than the test statistic then we reject the null hypothesis and assume that at least one of the three means is different.

For this run then, the test is:

0.9874 - 0.09696 = 0.0178

Since 0.0178 is greater than the test statistic of 0.00834 we reject the null hypothesis, and

assume that at least one of the means is different. Since there is a difference then the test is conducted comparing the means between continuous review and instantaneous review, and then instantaneous review and periodic review. The test statistic for this test is 0.007358. The two tests then are:

0.9874 - 0.9731 = 0.0143

and

0.9731 - 0.9696 = 0.0035

The results show that the first test is greater than the test statistic, and thus there is a statistical difference between the continuous review policy when demand inter-arrivals are at one every 20 days. Alternatively, the results of the second test are less than the test statistic, and therefore there is no statistical difference between the instantaneous and periodic reordering policies. Finally then, for this run we conclude that the Continuous Review Policy outperforms the other two given the parameters under consideration.

It can be seen that the runs in which we failed to find a statistical difference in the ANOVA test again show no statistical difference. For the remaining 16 runs, the tests show a greater weight towards the higher mean being significantly statistically different.

	Test of Three		Test of Two			Ranking		
	Test Stat	Test 1-3	Test Stat	Test 1-2	Test 2-3	Highest		Lowest
20	0.00988	0.006714	0.008229	0.002823	0.003891	IR	CR	PR
19	0.008834	0.017839	0.007358	0.01435	0.00349	CR	IR	PR
18	0.011279	0.01934	0.009394	0.00897	0.01037	CR	IR	PR
17	0.010502	0.024509	0.008746	0.013805	0.010704	CR	IR	PR
16	0.008272	0.013176	0.00689	0.010554	0.002623	IR	CR	PR
15	0.009041	0.016224	0.00753	0.011707	0.004517	IR	CR	PR
14	0.007564	0.016686	0.0063	0.001491	0.015195	IR	CR	PR
13	0.008197	0.000594	0.006826	0.000546	4.88E-05	IR	CR	PR
12	0.007976	0.001929	0.006643	0.001071	0.000858	IR	CR	PR
11	0.006918	0.010597	0.005762	0.008012	0.002585	IR	PR	CR
10	0.008093	0.015991	0.00674	0.01122	0.004771	IR	CR	PR
9	0.008625	0.004141	0.007183	0.001071	0.00307	CR	PR	IR
8	0.007686	0.010363	0.006401	0.005107	0.005256	IR	PR	CR
7	0.008579	0.009304	0.007145	0.007506	0.001798	PR	IR	CR
6	0.006406	0.009813	0.005335	0.009622	0.000191	PR	CR	IR
5	0.006699	0.011092	0.005579	0.010507	0.000585	PR	CR	IR
4	0.004964	0.008505	0.004134	0.00586	0.002645	PR	IR	CR
3	0.004339	0.014611	0.003614	0.006142	0.00847	PR	CR	IR
2	0.003064	0.011039	0.002552	0.00035	0.010689	PR	CR	IR
1	0.002272	0.012193	0.001892	0.001434	0.010759	CR	PR	IR

Table 4-22 - Newman-Kuels 98 Percent Service Level

Where a statistical difference exists (in 16 out of 20 runs) we can infer that the ordinal ranking is accurate, and that, while the two highest means may be equal, those two policies then perform equally well against the third. Generally, the periodic review reorder policy under-performs the other two policies under conditions of slow demand while the periodic review policy outperforms the other two policies when demand is greater in relation to lead-time. The continuous review policy appears to perform consistently well regardless of the demand arrival pattern.

This result seems to be due to a couple factors. First, the periodic review policy perhaps underperforms in conditions of slow demand when the time between demands is close to or greater than the review period. It seems that in these instances there exists greater variability in demands between review periods. Alternatively, an increased demand rate increases the predictability of demand.

The results of the Newman-Kuels test conducted on the runs when the target service level was 95 percent are shown in Table 4-23. Again, note that the Periodic

Review policy tends to under perform the other two when demand is slow, while it outperforms those policies when demands are more frequent.

	Test of Three		Test of Two			Ranking		
	Test Stat	Test 1-3	Test Stat	Test 1-2	Test 2-3	Highest		Lowest
20	0.012613	0.053621	0.010505	0.002688	0.050933	IR	CR	PR
19	0.012635	0.054535	0.010523	0.000854	0.053681	IR	CR	PR
18	0.012912	0.013161	0.010753	0.010715	0.002446	IR	PR	CR
17	0.011714	0.010666	0.009756	0.001607	0.009059	IR	CR	PR
16	0.011223	0.024525	0.009347	0.005784	0.018741	CR	IR	PR
15	0.013356	0.027332	0.011123	0.011394	0.015938	CR	IR	PR
14	0.013666	0.019936	0.011381	0.01377	0.006166	PR	CR	IR
13	0.009986	0.024931	0.008317	0.015463	0.009468	IR	CR	PR
12	0.010205	0.033371	0.008499	0.010793	0.022579	IR	CR	PR
11	0.009916	0.01156	0.008258	0.006364	0.005196	IR	PR	CR
10	0.011053	0.014211	0.009206	0.007011	0.007199	CR	IR	PR
9	0.011855	0.025244	0.009874	0.016689	0.008555	IR	PR	CR
8	0.010598	0.006914	0.008826	0.004848	0.002066	PR	CR	IR
7	0.009406	0.01488	0.007834	0.00631	0.00857	IR	PR	CR
6	0.010179	0.021546	0.008478	0.007954	0.013592	PR	CR	IR
5	0.011087	0.021923	0.009234	0.021161	0.000762	PR	IR	CR
4	0.009387	0.019169	0.007818	0.017018	0.002151	PR	IR	CR
3	0.006235	0.026498	0.005192	0.009761	0.016738	PR	CR	IR
2	0.004915	0.013672	0.004094	0.000552	0.013121	PR	CR	IR
1	0.00382	0.032224	0.003181	0.007044	0.02518	CR	PR	IR

Table 4-23- Newman-Keuls, 95% Service Level

When the target service level is at 92 percent the picture changes slightly. In this series it is seen (see Table 4-24) that the Instantaneous Reorder Policy dominates when demand is slowest. The Continuous Review Policy gains when demand inter-arrivals are once every 16 days or more frequently, with both the CR and IR policies exhibiting dominance over the periodic review policy. The Periodic Review policy again appears dominant when demands are more frequent, beginning with demands arriving every 7 days on average. Also of note is that when the target service level is 92 percent more tests result in significant differences between all three service policies (for instance, for the runs with demands every 20 days down to every 17 days.)

	Test of Three		Test of Two			Ranking		
	Test Stat	Test 1-3	Test Stat	Test 1-2	Test 2-3	Highest		Lowest
20	0.014435	0.0539	0.012022	0.02892	0.02498	IR	CR	PR
19	0.012753	0.057312	0.010621	0.025803	0.03151	IR	CR	PR
18	0.014552	0.06641	0.01212	0.033454	0.032957	IR	CR	PR
17	0.015263	0.073079	0.012712	0.030428	0.042651	IR	CR	PR
16	0.011505	0.024415	0.009582	0.006447	0.017968	CR	IR	PR
15	0.013326	0.027439	0.011098	0.011932	0.015507	CR	IR	PR
14	0.0158	0.029981	0.013159	0.006192	0.023789	CR	IR	PR
13	0.015738	0.038307	0.013107	0.012796	0.02551	CR	IR	PR
12	0.012683	0.035938	0.010563	0.035733	0.000204	IR	PR	CR
11	0.011659	0.044759	0.00971	0.01149	0.033269	IR	CR	PR
10	0.010924	0.012231	0.009098	0.007723	0.004509	IR	PR	CR
9	0.014411	0.00919	0.012002	0.002719	0.006471	CR	IR	PR
8	0.012915	0.024641	0.010756	0.019454	0.005187	IR	CR	PR
7	0.012611	0.020108	0.010503	0.005502	0.014606	PR	CR	IR
6	0.009539	0.025292	0.007944	0.019406	0.005886	PR	IR	CR
5	0.011243	0.011821	0.009364	2.77E-05	0.011793	PR	IR	CR
4	0.011305	0.028836	0.009415	0.023003	0.005832	PR	CR	IR
3	0.00856	0.014024	0.007129	0.011173	0.002851	PR	IR	CR
2	0.006788	0.021972	0.005653	0.004697	0.017275	CR	PR	IR
1	0.005785	0.04528	0.004818	0.015544	0.029736	CR	PR	IR

Table 4-24 - Newman-Kuels, 92% Service Level

Finally, Table 4-25 reflects the results of the Newman-Kuels test when the target service level is 85 percent. The results in this series are the most significantly different such that in those cases where there is a statistical difference with at least one mean, both the periodic review policy and the instantaneous reorder policies sharing dominance throughout.

	Test of Three		Test of Two			Ranking		
	Test Stat	Test 1-3	Test Stat	Test 1-2	Test 2-3	Highest		Lowest
20	0.019809	0.092348	0.016498	0.021165	0.071183	IR	CR	PR
19	0.0188	0.022751	0.015657	0.00559	0.017161	PR	IR	CR
18	0.01675	0.033917	0.01395	0.017942	0.015975	PR	IR	CR
17	0.016999	0.015527	0.014157	0.01305	0.002477	PR	CR	IR
16	0.020536	0.016764	0.017104	0.001151	0.015613	PR	CR	IR
15	0.018725	0.093476	0.015595	0.026282	0.067195	IR	CR	PR
14	0.015913	0.022672	0.013253	0.017923	0.004749	IR	CR	PR
13	0.016854	0.025748	0.014036	0.018927	0.006821	IR	CR	PR
12	0.017353	0.031613	0.014452	0.021861	0.009752	IR	CR	PR
11	0.016768	0.037187	0.013965	0.026823	0.010363	PR	IR	CR
10	0.013929	0.053945	0.011601	0.051355	0.00259	IR	CR	PR
9	0.015708	0.033326	0.013082	0.007544	0.025782	IR	PR	CR
8	0.01794	0.023155	0.014941	0.006191	0.016964	IR	PR	CR
7	0.015785	0.040563	0.013147	0.022058	0.018505	IR	PR	CR
6	0.017937	0.020094	0.014939	0.019157	0.000937	PR	IR	CR
5	0.017582	0.041545	0.014643	0.039369	0.002176	PR	IR	CR
4	0.012834	0.036216	0.010689	0.020086	0.01613	IR	PR	CR
3	0.012927	0.010035	0.010766	0.003564	0.00647	IR	PR	CR
2	0.011398	0.030839	0.009492	0.015365	0.015475	PR	CR	IR
1	0.008273	0.060961	0.00689	0.040888	0.020072	CR	PR	IR

Table 4-25 - Newman-Kuels, 85% Service Level

SUMMARY

This chapter has presented the data and the analytical techniques used in conducting the analysis. Additionally, the research questions were examined, and the results presented. This analysis has shown that the various policies behave in general as expected given the theoretical constructs. It also has shown that the policies do not have a degradation in performance when interacting with other ordering policies, and in fact show an improvement in performance in certain conditions. Finally, it was shown that as the customer demand rates vary different ordering policies dominate. The following chapter summarizes the results, draws conclusions on those results, and identifies future avenues of research based on this current research stream.

Chapter 5

CONCLUSIONS AND FURTHER RESEARCH

The past chapters have laid the foundation for the research, explored the extant literature on inventory policy, simulation, and safety stock, and discussed the relevance of this research to the operational environment of the Department of Defense. In addition, Chapter Three presented the methodology followed in the conduct of this research, explained why the variables of interest were chosen, and what specific modeling approaches were followed to operationalize the theoretical constructs in the simulation model under consideration. Finally, Chapter Four presented the data from the running of the simulation and the analysis conducted on that data. This chapter summarizes the findings, discusses the conclusions drawn, and presents further avenues of research that can be explored based on the initial work presented here.

This research has been directed by four research questions. Those questions are:

5. Does a difference exist between expected and realized customer service levels for the individual retail establishments? This question can be considered regardless of whether each retail establishment has chosen identical customer service targets or not. This question is treated in two parts.

    1A. First, given the parameters and assumptions used, does each individual policy meet the theoretically expected values, and;

1B. Second, when the fully integrated, and interactive model is run, does the performance of each ordering policy meet the theoretically expected values?

6. If a difference exists between the theoretical expected value and that actually achieved, does a difference then exist between the performance of a given policy when no competing policies exist and when the fully interactive model is used?
7. Do varied ordering policies at the retail level result in differing service levels between the retail establishments? This question is applicable when the retail establishments have each established their safety stock and ordering quantities based on identical service level goals.
8. If a difference exists between expected and realized customer service levels, does one retail level ordering/review policy tend to outperform other policies? This question takes this process from a purely descriptive research effort and begins to look at the prescriptive aspects.

Each of these research questions will now be discussed.

Summary of Findings

Research Question One sought to determine if there was a significant difference between the behavior of the individual models and the theoretical predictions of those models. This question looked both at the behavior of the models when they were run individually and when they were run in the interactive, full model. One-tailed t-tests

were run against the data testing the hypothesis that the mean service level values achieved in the model were equal to, or greater than, the theoretical target service levels.

It was seen from the testing of each of these policies that when run as independent models the policies generally perform at or above the target service level. Additionally, a saw-tooth behavior was observed and is resultant from the necessity to round up to ensure service levels are equal to, or greater than, the target service level. This leads us to conclude that the model, and its components, are generally behaving in a fashion consistent with theory. The variation seen between demand inter-arrival times can largely be attributed to the rounding up of the reorder points, which means that the same reorder point integer value is used for several demand inter-arrival times under consideration. As noted previously, this rounding up is to ensure that the achieved values are greater than or equal to the target service levels, and this behavior is thus consistent with the expected behavior.

Research Question Two looked at the actual performance of the policies, comparing their achieved performance when run independently with their performance when run as part of the interactive full model. Given the nature of this question and the hypotheses, two tests of hypothesis were run. The first was a two-tailed test to determine if the means between the two groups were equal. The second was the one-tailed test to determine if, in those instances when there was a difference, the performance of the policy in the full model was actually better than the performance of the policy when it is run by itself.

In fact, we can then conclude that for the performance of these models in these instances the ordering policies in these instances performed better in the interactive model than when no interactions between policies are present (in the independent model.)

Only thirteen of the tests of hypothesis resulted in a rejection of the null hypothesis. This leads to the conclusion that generally the policies are not impacted by interactions in the supply chain with other competing reordering policies at other retail facilities. Additionally, when the one-tailed test of hypothesis was conducted on those thirteen, it was determined that in fact the policies performed better (for those variable conditions of the test) when there was interaction with the other policies. Thus, the conclusion is drawn that, given the constraints and limitations of this model, there exists no negative impacts when retail establishments follow different ordering policies.

The Third and Fourth Research Questions sought to determine what if any difference existed between the three competing policies. After conducting the ANOVA test for the Third question, it was obvious that there existed differences between at least one of the means. For the Fourth question, the means were placed in Rank order, and the Newman-Kuels test was conducted. From this, it became clear that generally the Instantaneous and Continuous Review policies were dominant during slow demand, however the Periodic Review Policy was dominant as the demand rate increased.

Conclusions

This research is not limited in applicability to the military. Since the research focused on theoretical ordering policies commonly used in business the results of this research and any follow on research could be appropriately applied. The following conclusions drawn from the research should be viewed in the broader view of any supply chain with slow moving items.

First, there is no significant difference between the performance of the policies when interacting either from their performance as the policy in sole use, or from their theoretical targets. Second, while it can be said that certain policies perform better than others in given demand conditions, each policy generally can be said to achieve the target service level. Third, it was seen that the necessity to round up the reordering point values had perhaps the greatest influence on the fluctuations of achieved service levels. This is unfortunate since for the given independent variables the reorder point is in essence fixed.

With the finding that each of the policies generally perform as expected against the theoretical mean service level values, it seems prudent that any decisions concerning which policy to follow should continue to be based on the economic and practical matters currently driving such choices. The instantaneous reordering policy generally has a lower cycle stock, however it also places the greatest number of orders, with the number of orders equaling the the demands placed. As a result, the instantaneous reorder policies typically carry higher transportation costs associated with the large number of single unit shipments. Given these points, this policy continues to make sense when the demand is slow, the cost of the item (or of storage) is high, or both.

Alternatively, the periodic review policy makes sense when there are significant obstacles hindering the ability to place orders at any time. The periodic review policy will place fewer orders than the instantaneous reorder policy, but could potentially place more orders than the continuous review policy. Periodic review remains a satisfactory policy when the visibility of the system precludes the continuous monitoring of inventory levels. This policy also makes sense in an environment where deliveries are limited, such as when ships are at sea, and following a continuous review policy is not an alternative.

Many of the traditional assumptions governing reorder policy choices have changed. With the explosion of the information age, and electronic data interchange (EDI), many of the traditional costs in the system have been dramatically reduced. Ordering costs are in fact negligible, so placing more frequent orders is easily off-set by the savings in reduced inventory, and thus reduced capital expenditure. Transportation costs have also undergone significant downward pressures with the deregulation of the transportation industry and the introduction of Federal Express and other overnight services. This research may allow for a reconsideration of reordering policies in light of these changes in the environment. No longer must a firm be held to limiting the transportation or ordering costs. Many of these costs would be considered in the traditional economic order quantity approach, resulting in a lower fixed order quantity. On the other hand, when the ability to receive deliveries or place orders is hindered by location and time, the ability to plan to a date certain remains a plausible reason for selecting the periodic review policy.

This research also opens the door for firms to explore more closely matching their ordering policies with the conditions of the various retail locations. If the environmental, business, or geographic conditions differ for a firm's various retail establishments, then other reordering policies should be considered given that the service levels customers receive can be expected to remain satisfactory. The decision of a firm to standardize the ordering policies across the firm may no longer be a valid one, and this research indicates that a decision by the DLA to direct all services to follow a single ordering policy will not result in improved service for all services.

This research also has implications for other industries where a third party supplier provides support and service to similar retail establishments. This is seen in the medical profession, airline maintenance operations, and local governments. For instance, hospitals may follow different inventory stocking and ordering policies depending on their unique situations. Third party suppliers can work with the hospitals to develop a policy that fits their unique situation without loss of service. The Airlines typically perform maintenance on their aircraft at their hub operating locations, or at central aircraft maintenance facilities. There are instances where aircraft require maintenance while out on the "spokes." This arrangement may call for a different ordering policy than is used at the central facilities, and this research provides the basis for setting up alternative policies without the loss of service.

It is worth noting here that Palm's Theorem seems to be sufficiently applicable to the consumable supply chain as well as the reparable supply chain. As noted in Chapter Three, the reordering policy for the Instantaneous Review policy was based on Palm's

Theorem. Given that this policy performed equal to or better than the theoretical target service level in virtually all instances, this application of Palm's Theorem seems to be appropriate. Further research may be warranted to assess the true applicability of this theorem to consumable demand items.

In looking back then to the original genesis of this research problem, it appears that if differences exist in the achieved service levels for the various military services, the problem is outside of the theoretical constructs of their reordering policies, given the assumptions contained in this model. There are a myriad of other interactions in the supply system alone, including competing policies between services, administrative and communications channels that vary depending on service and locale, as well as perhaps reliance on different logistics systems themselves.This model established what is perhaps the theoretical ideal for warehouse ordering. The warehouse is faced with lumpy demand in all conditions except when the retailers follow an instantaneous reorder policy. This creates a problem since the establishment of a reorder point with a fixed order quantity is dependent on placing the order *eaxctly* when the reorder point is reached. To account for this then, the warehouse in the research model followed a continuous review (s,S) policy, ordering the fixed order quantity plus adding to the order to account for any "undershoot." This performance ensured that the theoretical targets were met or exceeded by the warehouse.

If the warehouses (or intermediate suppliers) fail to account for the lumpiness of demand, and operate under a strict (s, Q) policy they could face periods of dwindling inventory. This in fact may be an insidious problem since the reductions in inventory

may be compensated for by "item managers" who notice a shortage, and place an "emergency" order to compensate.

Finally, this model did not consider the impacts of "one-time" increases in demand resulting from emergency requisitions or increased operations. If these changes are of sufficient duration and scope it is possible that reordering decisions are being made based on the wrong set of parameters. These too could have a deleterious impact on service.

Further Research

To ensure the research was both tractable and plausible the exponential distribution was chosen for the distribution of demand and of lead time. Additionally, the normality of the convolution of lead-time demand was assumed. Further research should be conducted to expand the results to determine if these finding are further generalizable.

Another area worth evaluating in further research is the impact of ordering policies on stock on hand. Clearly the different policies resulted in different reordering points and safety stock levels. This research could be extended to assess which policies tend to maintain lower inventories over time. That is, not just which policies set the lower reorder points and had the lowest safety stock levels, but which carried the least amount of inventory (cycle stock) over time. Further study of these simulations and their results should look at the cost impacts associated with these policies, including the costs of ordering, the transportation costs, and the capital costs associated with carrying inventory. When other factors are considered it is likely that the policy that provides the

highest service level (above the target service level) may not be the most efficient or appropriate.

This research had as its focus the impact of retail ordering policies on the retail achieved service level. Further research should look at the impacts on the total supply chain. For instance, does the introduction of an instantaneous reordering policy along with the periodic review and continuous review policies provide a dampening effect, this moderating the bull-whip effect, or is the bull-whip effect even present when various reordering policies are all at play?

As noted above, there are many other factors influence the supply chain. Several of these could be mirrored in this model in future research. For instance, it is possible that the demand rates varied for each of the services, compounding the problem faced when policies themselves are different. It may be of interest to determine what the impact on service levels might be when the retail establishments do not have identical parameters for either lead time or demand.

Finally, further research may be warranted to consider the applicability of Palm's Theorem to the consumable supply chain. Using this theorem applied to consumables allowed this research to determine an appropriate reorder point and safety stock level. This theorem may have further applicability to the consumable distribution chain. Retail areas where demand patterns may be a close fit with the theorem should be identified, and research conducted to determine if this theorem can be used to reduce the inventory in the total supply chain, and drive down the cost of capital associated with that inventory.

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Appendix A

SIMAN SIMULATION MODEL FILE

CONTINUOUS REVIEW POLICY

```
      SIMAN ARENA MODEL FILE
      Warehouse     ASSIGN:
Warehouse(Custbase)=Warehouse(CustBase)-1;        Remove stock from
Warehouse
      0$            BRANCH,        1:
                                    If,CustBase<2,consume2,Yes:
                                    Else,7$,Yes;
Conduct Continuous Rvw, else Consume Periodic Review
      Consume2      DISPOSE;
final consumption of item

      7$            BRANCH,        1:
                                    If,Custbase<9,pointOfSale,Yes:
                                    Else,1$,Yes;
      PointOfSale   VBA:           6,vba;
      makeOrder     ASSIGN:
OnOrder(CustBase)=OnOrder(CustBase)+OrderQuantity(CustBase); Increment
order counters, and set flag indicating order in process.
      3$            BRANCH,:       Always,DepotStart,Yes:
                                    Always,12$,Yes;
      DepotStart    BRANCH,        1:
                                    If,Depot+DepotOnOrder-
OrderQuantity(CustBase)<=DepotReorder,11$,Yes:
                                    Else,Consume2,Yes;
      11$           COUNT:         DepotOrders,1;
      13$           ASSIGN:        DepotOrderSize=DepotOrderQuantity +
DepotReOrder - Depot;
      6$            ASSIGN:
DepotOnOrder=DepotOrderSize+DepotOnOrder;
      4$            DELAY:         EXPO(SupplierLT, Supplier Fill);
      5$            ASSIGN:        DepotOnOrder=DepotOnOrder-
DepotOrderSize:

Depot=Depot+DepotOrderSize:NEXT(Consume2);

      12$           VBA:           5,vba;
      PRDepotQ      QUEUE,         PRDepotQ;
```

```
      14$            SCAN:            Depot>=PROrderQuantity;
      DepotFill      ASSIGN:          Depot=Depot-PROrderQuantity;
      2$             DELAY:           Expo(DepotLT, Depot Fill);
      9$             VBA:             2,vba;
      8$             VBA:             1,vba:NEXT(Consume2);

      1$             ASSIGN:
OrderQuantity(CustBase)=1:NEXT(MakeOrder);


      ;
      ;
      ;      Model statements for module:  Arrive 6
      ;

      54$            CREATE,          1:EXPO(ArrivalRate, CR
Arrival):MARK(Enter);
      55$            ASSIGN:          TotalOrders2=TotalOrders2+1:
                                      CustBase=4;

      15$            STATION,         Cust 2;
      63$            TRACE,           -1,"-Arrived to system at station
Cust 2\n"::
      39$            DELAY:           0.;
      52$            ASSIGN:          Picture=0;
      78$            COUNT:           Cust 2_C,1;
      67$            TRACE,           -1,"-Transferred to next
module\n"::NEXT(10$);

      10$            VBA:             4,vba:NEXT(Consume2);
4

      PRmakeOrder    ASSIGN:
OnOrder(CustBase)=OnOrder(CustBase)+PROrderQuantity:NEXT(3$); Increment
order counters, and set flag indicating order in process.
```

PERIODIC REVIEW POLICY

```
      Warehouse      ASSIGN:
Warehouse(Custbase)=Warehouse(CustBase)-1;        Remove stock from
Warehouse
      0$             BRANCH,        1:
                                    If,CustBase<2,consume2,Yes:
                                    Else,7$,Yes;
Conduct Continuous Rvw, else Consume Periodic Review
      Consume2       DISPOSE;
final consumption of item

      7$             BRANCH,        1:
                                    If,Custbase<9,pointOfSale,Yes:
                                    Else,1$,Yes;
      PointOfSale    VBA:           6,vba;
      makeOrder      ASSIGN:
OnOrder(CustBase)=OnOrder(CustBase)+OrderQuantity(CustBase); Increment
order counters, and set flag indicating order in process.
      3$             BRANCH,:       Always,DepotStart,Yes:
                                    Always,12$,Yes;
      DepotStart     BRANCH,        1:
                                    If,Depot+DepotOnOrder-
OrderQuantity(CustBase)<=DepotReorder,11$,Yes:
                                    Else,Consume2,Yes;
      11$            COUNT:         DepotOrders,1;
      13$            ASSIGN:        DepotOrderSize=DepotOrderQuantity +
DepotReOrder - Depot;
      6$             ASSIGN:
DepotOnOrder=DepotOrderSize+DepotOnOrder;
      4$             DELAY:         EXPO(SupplierLT, Supplier Fill);
      5$             ASSIGN:        DepotOnOrder=DepotOnOrder-
DepotOrderSize:

Depot=Depot+DepotOrderSize:NEXT(Consume2);

      12$            VBA:           5,vba;
      PRDepotQ       QUEUE,         PRDepotQ;
      15$            SCAN:          Depot>=PROrderQuantity;
      DepotFill      ASSIGN:        Depot=Depot-PROrderQuantity;
      2$             DELAY:         Expo(DepotLT, Depot Fill);
      9$             VBA:           2,vba;
      8$             VBA:           1,vba:NEXT(Consume2);

      1$             ASSIGN:
OrderQuantity(CustBase)=1:NEXT(MakeOrder);


      ;
      ;
```

```
;       Model statements for module:  Arrive 8
;

55$            CREATE,        1:EXPO(ArrivalRate,  PR
Arrival):MARK(Enter);
56$            ASSIGN:        CustBase=1;

16$            STATION,       Cust 1;
64$            TRACE,         -1,"-Arrived to system at station
Cust 1\n":;
40$            DELAY:         0.;
53$            ASSIGN:        Picture=0;
79$            COUNT:         Cust 1_C,1;
68$            TRACE,         -1,"-Transferred to next
module\n"::NEXT(10$);

10$            VBA:           4,vba:NEXT(Consume2);
4


;
;
;       Model statements for module:  Arrive 9
;

134$           CREATE,        1,14:14:MARK(Enter);
135$           ASSIGN:        CustBase=1;

95$            STATION,       Arrive 4;
143$           TRACE,         -1,"-Arrived to system at station
Arrive 4\n":;
119$           DELAY:         0.;
147$           TRACE,         -1,"-Transferred to next
module\n"::NEXT(14$);

14$            VBA:           7,vba:NEXT(MakeOrder);

PRmakeOrder    ASSIGN:
OnOrder(CustBase)=OnOrder(CustBase)+PROrderQuantity:NEXT(3$); Increment
order counters, and set flag indicating order in process.
```

INSTANTANEOUS REVIEW POLICY

```
      Warehouse      ASSIGN:
Warehouse(Custbase)=Warehouse(CustBase)-1;        Remove stock from
Warehouse
      0$             BRANCH,        1:
                                    If,CustBase<2,consume2,Yes:
                                    Else,7$,Yes;
Conduct Continuous Rvw, else Consume Periodic Review
      Consume2       DISPOSE;
final consumption of item

      7$             BRANCH,        1:
                                    If,Custbase<9,pointOfSale,Yes:
                                    Else,1$,Yes;
      PointOfSale    VBA:           6,vba;
      makeOrder      ASSIGN:
OnOrder(CustBase)=OnOrder(CustBase)+OrderQuantity(CustBase); Increment
order counters, and set flag indicating order in process.
      3$             BRANCH,:       Always,DepotStart,Yes:
                                    Always,12$,Yes;
      DepotStart     BRANCH,        1:
                                    If,Depot+DepotOnOrder-
OrderQuantity(CustBase)<=DepotReorder,11$,Yes:
                                    Else,Consume2,Yes;
      11$            COUNT:         DepotOrders,1;
      13$            ASSIGN:        DepotOrderSize=DepotOrderQuantity +
DepotReOrder - Depot;
      6$             ASSIGN:
DepotOnOrder=DepotOrderSize+DepotOnOrder;
      4$             DELAY:         EXPO(SupplierLT, Supplier Fill);
      5$             ASSIGN:        DepotOnOrder=DepotOnOrder-
DepotOrderSize:

Depot=Depot+DepotOrderSize:NEXT(Consume2);

      12$            VBA:           5,vba;
      PRDepotQ       QUEUE,         PRDepotQ;
      14$            SCAN:          Depot>=PROrderQuantity;
      DepotFill      ASSIGN:        Depot=Depot-PROrderQuantity;
      2$             DELAY:         Expo(DepotLT, Depot Fill);
      9$             VBA:           2,vba;
      8$             VBA:           1,vba:NEXT(Consume2);

      1$             ASSIGN:
OrderQuantity(CustBase)=1:NEXT(MakeOrder);


      ;
      ;
```

```
      ;       Model statements for module:  Arrive 7
      ;

      54$            CREATE,        1:EXPO(ArrivalRate, IR
Arrival):MARK(Enter);
      55$            ASSIGN:        CustBase=7;

      15$            STATION,       Cust 3;
      63$            TRACE,         -1,"-Arrived to system at station
Cust 3\n":;
      39$            DELAY:         0.;
      78$            COUNT:         Cust 3_C,1;
      67$            TRACE,         -1,"-Transferred to next
module\n"::NEXT(10$);

      10$            VBA:           4,vba:NEXT(Consume2);
4

      PRmakeOrder    ASSIGN:
OnOrder(CustBase)=OnOrder(CustBase)+PROrderQuantity:NEXT(3$); Increment
order counters, and set flag indicating order in process.
```

FULL MODEL -- ALL THREE POLICIES

```
      Warehouse      ASSIGN:
Warehouse(Custbase)=Warehouse(CustBase)-1;          Remove stock from
Warehouse
      0$             BRANCH,        1:
                                    If,CustBase<2,consume2,Yes:
                                    Else,7$,Yes;
Conduct Continuous Rvw, else Consume Periodic Review
      Consume2       DISPOSE;
final consumption of item

      7$             BRANCH,        1:
                                    If,Custbase<9,pointOfSale,Yes:
                                    Else,1$,Yes;
      PointOfSale    VBA:           6,vba;
      makeOrder      ASSIGN:
OnOrder(CustBase)=OnOrder(CustBase)+OrderQuantity(CustBase); Increment
order counters, and set flag indicating order in process.
      3$             BRANCH,:       Always,DepotStart,Yes:
                                    Always,12$,Yes;
      DepotStart     BRANCH,        1:
                                    If,Depot+DepotOnOrder-
OrderQuantity(CustBase)<=DepotReorder,11$,Yes:
                                    Else,Consume2,Yes;
      11$            COUNT:         DepotOrders,1;
      13$            ASSIGN:        DepotOrderSize=DepotOrderQuantity +
DepotReOrder - Depot;
      6$             ASSIGN:
DepotOnOrder=DepotOrderSize+DepotOnOrder;
      4$             DELAY:         EXPO(SupplierLT, Supplier Fill);
      5$             ASSIGN:        DepotOnOrder=DepotOnOrder-
DepotOrderSize:

Depot=Depot+DepotOrderSize:NEXT(Consume2);

      12$            VBA:           5,vba;
      PRDepotQ       QUEUE,         PRDepotQ;
      15$            SCAN:          Depot>=PROrderQuantity;
      DepotFill      ASSIGN:        Depot=Depot-PROrderQuantity;
      2$             DELAY:         Expo(DepotLT, Depot Fill);
      9$             VBA:           2,vba;
      8$             VBA:           1,vba:NEXT(Consume2);

      1$             ASSIGN:
OrderQuantity(CustBase)=1:NEXT(MakeOrder);
```

```
     ;
     ;
     ;     Model statements for module:  Arrive 6
     ;

     55$            CREATE,        1:EXPO(ArrivalRate, CR
Arrival):MARK(Enter);
     56$            ASSIGN:        TotalOrders2=TotalOrders2+1:
                                   CustBase=4;

     16$            STATION,       Cust 2;
     64$            TRACE,         -1,"-Arrived to system at station
Cust 2\n":;
     40$            DELAY:         0.;
     53$            ASSIGN:        Picture=0;
     79$            COUNT:         Cust 2_C,1;
     68$            TRACE,         -1,"-Transferred to next
module\n"::NEXT(10$);

     10$            VBA:           4,vba:NEXT(Consume2);          4


     ;
     ;
     ;     Model statements for module:  Arrive 7
     ;

     134$           CREATE,        1:EXPO(ArrivalRate, IR
Arrival):MARK(Enter);
     135$           ASSIGN:        CustBase=7;

     95$            STATION,       Cust 3;
     143$           TRACE,         -1,"-Arrived to system at station
Cust 3\n":;
     119$           DELAY:         0.;
     158$           COUNT:         Cust 3_C,1;
     147$           TRACE,         -1,"-Transferred to next
module\n"::NEXT(10$);


     ;
     ;
     ;     Model statements for module:  Arrive 8
     ;

     213$           CREATE,        1:EXPO(ArrivalRate,  PR
Arrival):MARK(Enter);
     214$           ASSIGN:        CustBase=1;

     174$           STATION,       Cust 1;
     222$           TRACE,         -1,"-Arrived to system at station
Cust 1\n":;
     198$           DELAY:         0.;
```

```
     211$          ASSIGN:        Picture=0;
     237$          COUNT:         Cust 1_C,1;
     226$          TRACE,         -1,"-Transferred to next
module\n"::NEXT(10$);


     ;
     ;
     ;     Model statements for module:  Arrive 9
     ;

     292$          CREATE,        1,14:14:MARK(Enter);
     293$          ASSIGN:        CustBase=1;

     253$          STATION,       Arrive 4;
     301$          TRACE,         -1,"-Arrived to system at station
Arrive 4\n":;
     277$          DELAY:         0.;
     305$          TRACE,         -1,"-Transferred to next
module\n"::NEXT(14$);

     14$           VBA:           7,vba:NEXT(MakeOrder);

     PRmakeOrder   ASSIGN:
OnOrder(CustBase)=OnOrder(CustBase)+PROrderQuantity:NEXT(3$); Increment
order counters, and set flag indicating order in process.
```

Appendix B

SIMAN EXPERIMENT FILES

CONTINOUS REVIEW POLICY

```
BEGIN,          No,No;

PROJECT,        Multi echelon Inventory Model,Steve Brady,8/24/1997,Yes;

ATTRIBUTES:     PROrderQuantity,:
                Enter:
                CustBase,:
                DepotOrderSize;

VARIABLES:      TotalOrders3:
                SS,:
                SupplierLT,:
                OrderQuantity(9):
                partialQ,:
                DepotLT,:
                DepotReorder,:
                Gk:
                OnOrder(9),0:
                MaxInvLevel:
                ReorderPt,:
                DepotOnOrder,0:
                ReviewPeriod:
                LeadTimeFlag:
                ArrivalRate,:
                Warehouse(9),5,5,5,5,5,5,2,2,2:
                DepotSS:
                DemandVar:
                TotalOrders1:
                DepotOrderQuantity,75:
                TotalOrders2:
                Depot,50:
                BackOrdered(9);

SEEDS:          Supplier Fill,,Common:
                IR Arrival,,Common:
                PR Arrival,,Common:
                CR Arrival,,Common:
                Depot Fill,,Common;
```

```
QUEUES:        CustomerLine3a,FirstInFirstOut:
               CustomerLine2a,FirstInFirstOut:
               CustomerLine1a,FirstInFirstOut:
               PrDepotQ,FirstInFirstOut:
               DepotQ,FIFO;

RESOURCES:     DepotFill,Capacity(150,),-,Stationary:
               OrderProcessing,Capacity(150,),-,Stationary;

STATIONS:      Cust 2;

COUNTERS:      PROutOfStock,,Replicate:
               JITOutOfStock,,Replicate,"JITOutOfStock.dat":
               NumberOfOrders,,Replicate,"NumberOfOrders.dat":
               CROutOfStock,,Replicate,"CR Out of Stock":
               DepotOutOfStock,,Replicate:
               OutOfStock3a,,Replicate,"OutOfStock3a.dat":
               OutOfStock2a,,Replicate,"OutOfStock2a.dat":
               Cust 1_C,,Replicate:
               UnitsOrdered,,Replicate:
               OutOfStock1a,,Yes,"OutOfStock1a.dat":
               LeadTimeCounter,,Replicate:
               DepotOrders,,Replicate:
               Cust 2_C,,Replicate:
               Cust 3_C,,Replicate;

TALLIES:       1,LeadTimePR:
               2,LeadTimeCR,"LeadTimeCR.dat":
               3,LeadTimeIR:
               4,TimeInSystem,"TimeInSystemCR.dat";

DSTATS:        Warehouse(4),,"warehouse4.dat":
               NQ(DepotQ),,"Depot1.dat":
               NQ(CustomerLine2a),# in CustomerLine2a,"Cline2a.dat":
               BackOrdered(7),,"BackOrdered 7.dat":
               Warehouse(7),,"Warehouse 7.dat":
               BackOrdered(4),Backordered 4,"Backordered 4.dat":
               MR(OrderProcessing),,"Order Processing":
               NQ(PrDepotQ),,"PRDepotQ.dat":
               Depot,,"DepotLevels.dat";

REPLICATE,     5,0.0,500,Yes,Yes,0.0;

REPORTS:       Tally Standard Deviation,STDOUT,Tally Standard
Deviation,,Unsorted,Free;

REPORTLINES:   Tally Average,Tally Standard Deviation,"Lead Time and Std
Dev     %f   %f",TAVG(LeadTimeCR),TSTD(LeadTimeCR);
         (Do not type text in this document beyond here)
```

PERIODIC REVIEW POLICY

```
BEGIN,          No,No;

PROJECT,        Multi echelon Inventory Model,Steve Brady,8/24/1997,Yes;

ATTRIBUTES:     PROrderQuantity,:
                Enter:
                CustBase,:
                DepotOrderSize;

VARIABLES:      TotalOrders3:
                SS,:
                SupplierLT,:
                OrderQuantity(9):
                partialQ,:
                DepotLT,:
                DepotReorder,:
                Gk:
                OnOrder(9),0:
                MaxInvLevel:
                ReorderPt,:
                DepotOnOrder,0:
                ReviewPeriod:
                LeadTimeFlag:
                ArrivalRate,:
                Warehouse(9),5,5,5,5,5,5,2,2,2:
                DepotSS:
                DemandVar:
                TotalOrders1:
                DepotOrderQuantity,75:
                TotalOrders2:
                Depot,50:
                BackOrdered(9);

SEEDS:          Supplier Fill,,Common:
                IR Arrival,,Common:
                PR Arrival,,Common:
                CR Arrival,,Common:
                Depot Fill,,Common;

QUEUES:         CustomerLine3a,FirstInFirstOut:
                CustomerLine2a,FirstInFirstOut:
                CustomerLine1a,FirstInFirstOut:
                PrDepotQ,FirstInFirstOut:
                DepotQ,FIFO;

RESOURCES:      DepotFill,Capacity(150,),-,Stationary:
                OrderProcessing,Capacity(150,),-,Stationary;

STATIONS:       Cust 1:
                Arrive 4;
```

```
COUNTERS:       PROutOfStock,,Replicate:
                JITOutOfStock,,Replicate,"JITOutOfStock.dat":
                NumberOfOrders,,Replicate,"NumberOfOrders.dat":
                CROutOfStock,,Replicate,"CR Out of Stock":
                DepotOutOfStock,,Replicate:
                OutOfStock3a,,Replicate,"OutOfStock3a.dat":
                OutOfStock2a,,Replicate,"OutOfStock2a.dat":
                Cust 1_C,,Replicate:
                UnitsOrdered,,Replicate:
                OutOfStock1a,,Yes,"OutOfStock1a.dat":
                LeadTimeCounter,,Replicate:
                DepotOrders,,Replicate:
                Cust 2_C,,Replicate:
                Cust 3_C,,Replicate;

TALLIES:        1,LeadTimePR:
                2,LeadTimeCR,"LeadTimeCR.dat":
                3,LeadTimeIR:
                4,TimeInSystem,"TimeInSystemCR.dat";

DSTATS:         BackOrdered(1),,"BackOrdered 1.dat":
                NQ(DepotQ),,"Depot1.dat":
                Warehouse(1),,"Warehouse 1.dat":
                NQ(CustomerLine2a),# in CustomerLine2a,"Cline2a.dat":
                MR(OrderProcessing),,"Order Processing":
                NQ(PrDepotQ),,"PRDepotQ.dat":
                Depot,,"DepotLevels.dat";

REPLICATE,      5,0.0,500,Yes,Yes,0.0;

REPORTS:        Tally Standard Deviation,STDOUT,Tally Standard
Deviation,,Unsorted,Free;

REPORTLINES:  Tally Average,Tally Standard Deviation,"Lead Time and Std
Dev    %f  %f",TAVG(LeadTimeCR),TSTD(LeadTimeCR);
```

INSTANTANEOUS REVIEW POLICY

```
BEGIN,          No,No;

PROJECT,        Multi echelon Inventory Model,Steve Brady,8/24/1997,Yes;

ATTRIBUTES:     PROrderQuantity,:
                Enter:
                CustBase,:
                DepotOrderSize;

VARIABLES:      TotalOrders3:
                SS,:
                SupplierLT,:
                OrderQuantity(9):
                partialQ,:
                DepotLT,:
                DepotReorder,:
                Gk:
                OnOrder(9),0:
                MaxInvLevel:
                ReorderPt,:
                DepotOnOrder,0:
                ReviewPeriod:
                LeadTimeFlag:
                ArrivalRate,:
                Warehouse(9),5,5,5,5,5,5,2,2,2:
                DepotSS:
                DemandVar:
                TotalOrders1:
                DepotOrderQuantity,75:
                TotalOrders2:
                Depot,50:
                BackOrdered(9);

SEEDS:          Supplier Fill,,Common:
                IR Arrival,,Common:
                PR Arrival,,Common:
                CR Arrival,,Common:
                Depot Fill,,Common;

QUEUES:         CustomerLine3a,FirstInFirstOut:
                CustomerLine2a,FirstInFirstOut:
                CustomerLine1a,FirstInFirstOut:
                PrDepotQ,FirstInFirstOut:
                DepotQ,FIFO;

RESOURCES:      DepotFill,Capacity(150,),-,Stationary:
                OrderProcessing,Capacity(150,),-,Stationary;

STATIONS:       Cust 3;
```

```
COUNTERS:       PROutOfStock,,Replicate:
                JITOutOfStock,,Replicate,"JITOutOfStock.dat":
                NumberOfOrders,,Replicate,"NumberOfOrders.dat":
                CROutOfStock,,Replicate,"CR Out of Stock":
                DepotOutOfStock,,Replicate:
                OutOfStock3a,,Replicate,"OutOfStock3a.dat":
                OutOfStock2a,,Replicate,"OutOfStock2a.dat":
                Cust 1_C,,Replicate:
                UnitsOrdered,,Replicate:
                OutOfStock1a,,Yes,"OutOfStock1a.dat":
                LeadTimeCounter,,Replicate:
                DepotOrders,,Replicate:
                Cust 2_C,,Replicate:
                Cust 3_C,,Replicate;

TALLIES:        1,LeadTimePR:
                2,LeadTimeCR,"LeadTimeCR.dat":
                3,LeadTimeIR:
                4,TimeInSystem,"TimeInSystemCR.dat";

DSTATS:         NQ(DepotQ),,"Depot1.dat":
                BackOrdered(7),,"BackOrdered 7.dat":
                Warehouse(7),,"Warehouse 7.dat":
                MR(OrderProcessing),,"Order Processing":
                NQ(PrDepotQ),,"PRDepotQ.dat":
                Depot,,"DepotLevels.dat";

REPLICATE,      5,0.0,500,Yes,Yes,0.0;

REPORTS:        Tally Standard Deviation,STDOUT,Tally Standard
Deviation,,Unsorted,Free;

REPORTLINES:  Tally Average,Tally Standard Deviation,"Lead Time and Std
Dev    %f  %f",TAVG(LeadTimeCR),TSTD(LeadTimeCR);
```

FULL MODEL -- ALL THREE POLICIES

```
BEGIN,          No,No;

PROJECT,        Multi echelon Inventory Model,Steve Brady,8/24/1997,Yes;

ATTRIBUTES:     PROrderQuantity,:
                Enter:
                CustBase,:
                DepotOrderSize;

VARIABLES:      TotalOrders3:
                SS,:
                SupplierLT,:
                OrderQuantity(9):
                partialQ,:
                DepotLT,:
                DepotReorder,:
                Gk:
                OnOrder(9),0:
                MaxInvLevel:
                ReorderPt,:
                DepotOnOrder,0:
                ReviewPeriod:
                LeadTimeFlag:
                ArrivalRate,:
                Warehouse(9),5,5,5,5,5,5,2,2,2:
                DepotSS:
                DemandVar:
                TotalOrders1:
                DepotOrderQuantity,75:
                TotalOrders2:
                Depot,50:
                BackOrdered(9);

SEEDS:          Supplier Fill,,Common:
                IR Arrival,,Common:
                PR Arrival,,Common:
                CR Arrival,,Common:
                Depot Fill,,Common;

QUEUES:         CustomerLine3a,FirstInFirstOut:
                CustomerLine2a,FirstInFirstOut:
                CustomerLine1a,FirstInFirstOut:
                PrDepotQ,FirstInFirstOut:
                DepotQ,FIFO;

RESOURCES:      DepotFill,Capacity(150,),-,Stationary:
                OrderProcessing,Capacity(150,),-,Stationary;

STATIONS:       Cust 1:
```

```
                    Cust 2:
                    Cust 3:
                    Arrive 4;

      COUNTERS:     PROutOfStock,,Replicate:
                    JITOutOfStock,,Replicate,"JITOutOfStock.dat":
                    NumberOfOrders,,Replicate,"NumberOfOrders.dat":
                    CROutOfStock,,Replicate,"CR Out of Stock":
                    DepotOutOfStock,,Replicate:
                    OutOfStock3a,,Replicate,"OutOfStock3a.dat":
                    OutOfStock2a,,Replicate,"OutOfStock2a.dat":
                    Cust 1_C,,Replicate:
                    UnitsOrdered,,Replicate:
                    OutOfStock1a,,Yes,"OutOfStock1a.dat":
                    LeadTimeCounter,,Replicate:
                    DepotOrders,,Replicate:
                    Cust 2_C,,Replicate:
                    Cust 3_C,,Replicate;

      TALLIES:      1,LeadTimePR:
                    2,LeadTimeCR,"LeadTimeCR.dat":
                    3,LeadTimeIR:
                    4,TimeInSystem,"TimeInSystemCR.dat";

      DSTATS:       Warehouse(4),,"warehouse4.dat":
                    NQ(DepotQ),,"Depot1.dat":
                    NQ(CustomerLine2a),# in CustomerLine2a,"Cline2a.dat":
                    BackOrdered(7),,"BackOrdered 7.dat":
                    Warehouse(7),,"Warehouse 7.dat":
                    BackOrdered(4),Backordered 4,"Backordered 4.dat":
                    MR(OrderProcessing),,"Order Processing":
                    NQ(PrDepotQ),,"PRDepotQ.dat":
                    Depot,,"DepotLevels.dat";

      REPLICATE,    5,0.0,500,Yes,Yes,0.0;

      REPORTS:      Tally Standard Deviation,STDOUT,Tally Standard
Deviation,,Unsorted,Free;

      REPORTLINES:  Tally Average,Tally Standard Deviation,"Lead Time and Std
Dev    %f  %f",TAVG(LeadTimeCR),TSTD(LeadTimeCR);
```

Appendix C

VISUAL BASIC CODE

Model Code

NOTE: The code for each of the models is identical. The only exception is that when each model is run independently certain features or computations are not used.

```
Option Explicit
'
' Global variables. Code in the RunBeginSimulation event sets
their values at the
'  beginning of each run so that they need not be re-evaluated
each time an entity fires a VBA event.

'Last Modified, 10 April 99;
'Modified to accurately compute SS and ordering information for
each of the three policies
'


'Overall Model Setup
Dim g_Model As Arena.Model
Dim g_SIMAN As Arena.SIMAN

'Spreadsheet setup info
Dim g_XLInputFile As Integer
Dim g_XLOutputFile As Integer
Dim g_inputRow As Long
Dim g_OutputCol As Long
Dim g_outputRow, g_TimeSystemRow, g_CounterOutputRow As Long

'Customer Parameters
Dim g_ArrivalRate, g_DemandVar As Long
Dim ArrivalRate, DemandVar As Long
Dim OrderQuantity, CROrderQuantity, IROrderQuantity As Long
Dim IROP, ROP As Double

'Declare Depot Variables
Dim g_Depot, g_DepotOrderQuantity, g_DepotOnOrder, g_DepotReOrder
As Long
```

```
    'Declare Supplier Lead Time, Depot Lead Time to Retailer, Mean
Lead Time Demand, std Dev LTD
    Dim g_SupplierLT, g_LeadTimeVar, g_DepotLT As Long

    Dim g_OnOrder(9) As Integer
    Dim g_CustBase, g_Enter As Long
    Dim g_Warehouse(9), g_ReorderPt, g_OrderQuantity(9) As Integer

    'Declare variables used to track statistics
    Dim g_NumberOfOrders, g_OutOfStock1a, g_OutOfStock2a,
g_OutOfStock3a As Integer

    'Declare the safety stock factor and safety stock variables
    Dim g_k, SS, ServiceLevel, g_DepotSS As Double

    'Periodic Review Model period length and Maximum Inventory Level
    Dim g_PeriodReview, g_MaxInvLevel, g_partialQ As Long
    Dim PR_S, PR_SafetyStock As Integer

    Dim g_ArenaDir As String


    Private Sub ModelLogic_RunBegin()
        ' Set the global SIMAN variable
        Set g_Model = ThisDocument.Model
        'Run the menu display to set the variable values
        ModelSetup.Show

    End Sub

    Private Sub ModelLogic_RunBeginSimulation()
        Set g_SIMAN = g_Model.SIMAN

        'Declare the Loop variable used to fill in the labels on the
spreadsheet.
        Dim RepCount As Integer

    RepCount = 1
        'Set the number of replications and the length of each run
        g_SIMAN.RunMaximumReplications = ModelSetup.tbxReplicat
        g_SIMAN.RunEndTime = ModelSetup.tbxRunlength

        ' Set the global variables that store the index of the SIMAN
variable and attributes
        '  that will be used in the logic below
        g_NumberOfOrders = g_SIMAN.SymbolNumber("NumberOfOrders")

        g_CustBase = g_SIMAN.SymbolNumber("CustBase")
        g_Enter = g_SIMAN.SymbolNumber("Enter")
        g_ArrivalRate = g_SIMAN.SymbolNumber("ArrivalRate")
        g_Depot = g_SIMAN.SymbolNumber("Depot")

        g_ReorderPt = g_SIMAN.SymbolNumber("ReorderPt")
```

```
            g_partialQ = g_SIMAN.SymbolNumber("partialQ")
            g_k = g_SIMAN.SymbolNumber("Gk")
            SS = g_SIMAN.SymbolNumber("SS")
            g_MaxInvLevel = g_SIMAN.SymbolNumber("MaxInvLevel")
            g_PeriodReview = g_SIMAN.SymbolNumber("ReviewPeriod")

            g_DepotLT = g_SIMAN.SymbolNumber("DepotLT")
            g_DepotSS = g_SIMAN.SymbolNumber("DepotSS")
            g_SupplierLT = g_SIMAN.SymbolNumber("SupplierLT")
            g_DepotOnOrder = g_SIMAN.SymbolNumber("DepotOnOrder")
            g_DepotReOrder = g_SIMAN.SymbolNumber("DepotReorder")
            g_DepotOrderQuantity =
g_SIMAN.SymbolNumber("DepotOrderQuantity")


            ' Create the Excel spreadsheet for output
            ' Write headers to the output file
            g_XLOutputFile = smutils_NewExcelWorkbook
            'Insert the labels at the header columns on the spreadsheets
            While RepCount <= g_SIMAN.RunMaximumReplications
            With
smutils_XL.Workbooks(g_XLOutputFile).Worksheets("Sheet3")
                ' .Cells(1, RepCount * 3 - 2).value = "Cust #, Run " &
RepCount
                ' .Cells(1, RepCount * 3 - 1).value = "Arrival Time, Run
" & RepCount
                ' .Cells(1, RepCount * 3 - 0).value = "Inter Arrival
Time, Run" & RepCount
                .Cells(1, RepCount * 2 - 1).value = "Cust #, Run " &
RepCount
                .Cells(1, RepCount * 2 - 0).value = "Time in System, Run
" & RepCount
            End With
                RepCount = RepCount + 1
            Wend

            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "A1",
"Number of Orders PR"
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "B1",
"Stockouts, Base 1"
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "C1",
"Percent Fill Base 1"
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "D1",
"Number of Orders CR"
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "E1",
"Stockouts, Base 2"
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "F1",
"Percent Fill Base 2"
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "G1",
"Number of Orders JIT"
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "H1",
"Stockouts, Base 3"
```

```
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2",
"I1", "Percent Fill Base 3"
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "J1",
"Number of Orders Depot"
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "K1",
"Stockouts, Depot"
            smutils_WriteExcelValue g_XLOutputFile, "Sheet2", "L1",
"Percent Fill Base Depot"

            'Set initial positions for entering the data into the
spreadsheets
            g_outputRow = 2
            g_TimeSystemRow = 2
            g_CounterOutputRow = 2
            g_OutputCol = 1
      End Sub
      Private Sub ModelLogic_RunBeginReplication()

            'Enter the variables into the model from the form.
            Dim PRgk, PRgkNEW, PRk, p_CRk, f_CRk, CRgkNEW, PRSafetyStock,
CRgk, CRk, CRSafetyStock, IRgk, IRk, IRSafetyStock As Double
            Dim PRZ, p_PRk, f_PRk As Double
            Dim Dgk, Dk, p_Dk, f_Dk, DepotSafetyStock As Double
            Dim IRZ, p_IRk, f_IRk, IRgkNEW As Double
            Dim ActualLTMean, ActualLTStdDev As Double
            Dim DLeadTime, DArrivalRate, DepotOrderQuantity, DZ,
ReviewPd, DepotROP, SupplierLT As Long
            Dim CRZ, PRQ, Dummy, StockoutLevel, PRLTMean, LTandRP,
PRMLTD, PRSLTD, CRMLTD, CRSLTD, IRMLTD, IRSLTD, DepotMLTD, DepotSLTD,
DailyDemand, DepotDailyDemand As Double
            Dim DailyVariance, DepotMeanLT, DepotSTD As Double
            Dim PRLTSTD, PRLTStdDev As Double

            g_SIMAN.RunEndTime = ModelSetup.tbxRunlength

            With ModelSetup
                ArrivalRate = .tbxArrivalRate
                'DemandVar = .tbxDemandVar
                DailyDemand = (1 / .tbxArrivalRate)
                DailyVariance = (1 / .tbxDemandVar)
                DepotMeanLT = (.tbxDepotLT)
                DepotSTD = (.tbxLeadTimeVar)
                ActualLTMean = (.tbxLTMean)
                ActualLTStdDev = (.tbxLTVar)


                'Determine the Mean and Standard Deviations of Lead Time
Demand for each retail establishment/ordering policy
                'Values are computed using the formula for LTD
convolution listed in Silver, Pike and Peterson's
                '"Inventory Management and Production Planning and
Scheduling"
                'page 283.
                '
```

```
        'Demand is distributed exponentially, and so the
DailyVariance is the variance (equal to Lambda)
        'and is not squared.  The Lead Time computations are left
as standard Deviations since the
        'distributions are not necessarily exponential.


        CRMLTD = ((ActualLTMean) * DailyDemand)
        CRSLTD = (ActualLTMean * (DailyVariance)) + (DailyDemand
^ 2 * (ActualLTStdDev) ^ 2)

        IRMLTD = (DailyDemand) * DepotMeanLT
        IRSLTD = IRMLTD

        PR_S = 0


        'Basic information for the Model
        ServiceLevel = (.tbxP2service)
        CROrderQuantity = .tbxContReviewQ
        IROrderQuantity = .tbxIRReviewQ
        ReviewPd = .tbxReviewPeriod
        PRLTMean = (.tbxDepotLT)
        PRLTStdDev = (.tbxLeadTimeVar)


        'This computation for std dev of LT is provided in the
Johnson, et.al. article,
        ' "Expressions for Item Fill Rates in Periodic Inventory
Systems" in Naval Research Logistics, v 42, 1995
        'PRLTSTD = Sqr((LTandRP) * (DailyVariance) + (DailyDemand
^ 2) * DepotSTD ^ 2)

        'This computation for std dev of LT is from Dr Stenger
        PRLTSTD = PRLTStdDev
        LTandRP = 1 * ReviewPd + 1 * PRLTMean

        PRMLTD = (PRLTMean * DailyDemand)
        PRSLTD = (PRLTMean * (DailyVariance)) + (DailyDemand ^ 2
* (PRLTSTD ^ 2))

        PRQ = (ReviewPd * DailyDemand)
        StockoutLevel = 1 - ServiceLevel
        Dummy = (StockoutLevel) * (PRQ / (PRSLTD ^ 0.5))
        PRgk = Dummy
        PRZ = Sqr(Log(25 / Dummy ^ 2))
        PRk = ((-5.3925569) + (5.6211054 * PRZ) + ((-3.883683) *
(PRZ) ^ 2) + 1.0897299 * PRZ ^ 3) / (1 + (-0.72496485 * PRZ) +
(0.507326622 * (PRZ) ^ 2) + (0.0669136868 * (PRZ) ^ 3) + (-
0.00329129114 * (PRZ) ^ 4))

        If ((ReviewPd * DailyDemand) / Sqr(PRSLTD)) < 1 Then
            PRk = PRk + ((ReviewPd * DailyDemand) / Sqr(PRSLTD))
```

```
                        p_PRk = 1 -
smutils_XL.WorksheetFunction.NormSDist(PRk)
                        f_PRk = (1 / (Sqr(2 * 3.1415926))) * Exp(-(PRk ^ 2) /
2)
                        PRgkNEW = f_PRk - (p_PRk * PRk)
                        PRgk = (1 - ServiceLevel) * (PRQ / PRSLTD ^ 0.5) +
PRgkNEW
                        PRZ = Sqr(Log(25 / PRgk ^ 2))
                        PRk = ((-5.3925569) + (5.6211054 * PRZ) + ((-
3.883683) * (PRZ) ^ 2) + 1.0897299 * PRZ ^ 3) / (1 + (-0.72496485 *
PRZ) + (0.507326622 * (PRZ) ^ 2) + (0.0669136868 * (PRZ) ^ 3) + (-
0.00329129114 * (PRZ) ^ 4))
                    End If

                        PRSafetyStock = (PRk * Sqr(PRSLTD))
                    'PR_SafetyStock = (ReviewPd * DailyDemand) +
PRSafetyStock
                    PR_S = smutils_XL.WorksheetFunction.RoundUp(((ReviewPd *
DailyDemand) + PRMLTD + PRSafetyStock), 0)


                    'Continuous Review Computations


                    CRgk = (1 - ServiceLevel) * CROrderQuantity / Sqr(CRSLTD)
                    CRZ = Sqr(Log(25 / CRgk ^ 2))
                    CRk = ((-5.3925569) + (5.6211054 * CRZ) + ((-3.883683) *
(CRZ) ^ 2) + 1.0897299 * CRZ ^ 3) / (1 + (-0.72496485 * CRZ) +
(0.507326622 * (CRZ) ^ 2) + (0.0669136868 * (CRZ) ^ 3) + (-
0.00329129114 * (CRZ) ^ 4))



                    If ((CROrderQuantity) / Sqr(CRSLTD)) < 1 Then
                        CRk = CRk + ((CROrderQuantity) / Sqr(CRSLTD))
                        p_CRk = 1 -
smutils_XL.WorksheetFunction.NormSDist(CRk)
                        f_CRk = (1 / (Sqr(2 * 3.1415926))) * Exp(-(CRk ^ 2) /
2)
                        CRgkNEW = f_CRk - (p_CRk * CRk)
                        CRgk = (1 - ServiceLevel) * ((CROrderQuantity) /
CRSLTD ^ 0.5) + CRgkNEW
                        CRZ = Sqr(Log(25 / CRgk ^ 2))
                        CRk = ((-5.3925569) + (5.6211054 * CRZ) + ((-
3.883683) * (CRZ) ^ 2) + 1.0897299 * CRZ ^ 3) / (1 + (-0.72496485 *
CRZ) + (0.507326622 * (CRZ) ^ 2) + (0.0669136868 * (CRZ) ^ 3) + (-
0.00329129114 * (CRZ) ^ 4))
                    End If
                    CRSafetyStock = (CRk * Sqr(CRSLTD))
                    ROP = smutils_XL.WorksheetFunction.RoundUp((CRSafetyStock
+ CRMLTD), 0)

                    If ROP < 0 Then
                        ROP = 0
```

```
                End If

                'IR (s-1,S) policy computations

                IRgk = (1 - ServiceLevel) * IROrderQuantity / Sqr(IRSLTD)
                IRZ = Sqr(Log(25 / IRgk ^ 2))
                IRk = ((-5.3925569) + (5.6211054 * IRZ) + ((-3.883683) *
(IRZ) ^ 2) + 1.0897299 * IRZ ^ 3) / (1 + (-0.72496485 * IRZ) +
(0.507326622 * (IRZ) ^ 2) + (0.0669136868 * (IRZ) ^ 3) + (-
0.00329129114 * (IRZ) ^ 4))


                If ((IROrderQuantity) / Sqr(IRSLTD)) < 1 Then
                    IRk = IRk + ((IROrderQuantity) / Sqr(IRSLTD))
                    p_IRk = 1 -
smutils_XL.WorksheetFunction.NormSDist(IRk)
                    f_IRk = (1 / (Sqr(2 * 3.1415926))) * Exp(-(IRk ^ 2) /
2)
                    IRgkNEW = f_IRk - (p_IRk * IRk)
                    IRgk = (1 - ServiceLevel) * ((IROrderQuantity) /
IRSLTD ^ 0.5) + IRgkNEW
                    IRZ = Sqr(Log(25 / IRgk ^ 2))
                    IRk = ((-5.3925569) + (5.6211054 * IRZ) + ((-
3.883683) * (IRZ) ^ 2) + 1.0897299 * IRZ ^ 3) / (1 + (-0.72496485 *
IRZ) + (0.507326622 * (IRZ) ^ 2) + (0.0669136868 * (IRZ) ^ 3) + (-
0.00329129114 * (IRZ) ^ 4))
                End If
                IRSafetyStock = (IRk * Sqr(IRSLTD))
                IROP =
smutils_XL.WorksheetFunction.RoundUp((IRSafetyStock + (DailyDemand) *
DepotMeanLT), 0)

                If IROP < 0 Then
                    IROP = 0
                End If


                SupplierLT = (.tbxSupplierLT)
                DepotDailyDemand = 1 * (DailyDemand)
                'Assuming supplierLt is both mean and variance
                DLeadTime = .tbxDepotLT
                DArrivalRate = .tbxArrivalRate
                DepotOrderQuantity = .tbxDepotQ

                DepotMLTD = SupplierLT * DepotDailyDemand
                DepotSLTD = ((SupplierLT) * (1 * (DailyVariance))) +
(DepotDailyDemand ^ 2 * (SupplierLT ^ 2))
                Dgk = (1 - ServiceLevel) * (DepotOrderQuantity /
Sqr(DepotSLTD))
                DZ = Sqr(Log(25 / Dgk ^ 2))
                Dk = ((-5.3925569) + (5.6211054 * DZ) + ((-3.883683) *
(DZ) ^ 2) + 1.0897299 * DZ ^ 3) / (1 + (-0.72496485 * DZ) +
```

```
(0.507326622 * (DZ) ^ 2) + (0.0669136868 * (DZ) ^ 3) + (-
0.00329129114 * (DZ) ^ 4))

              If ((DepotOrderQuantity) / Sqr(DepotSLTD)) < 1 Then
                  Dk = Dk + ((DepotOrderQuantity) / Sqr(DepotSLTD))
                  p_Dk = 1 -
(smutils_XL.WorksheetFunction.NormSDist(Dk))
                  f_Dk = (1 / (Sqr(2 * 3.1415926))) * Exp(-(Dk ^ 2) /
2)

                  Dgk = f_Dk - (p_Dk * Dk)
                  DZ = Sqr(Log(25 / Dgk ^ 2))
                  Dk = ((-5.3925569) + (5.6211054 * DZ) + ((-3.883683)
* (DZ) ^ 2) + 1.0897299 * DZ ^ 3) / (1 + (-0.72496485 * DZ) +
(0.507326622 * (DZ) ^ 2) + (0.0669136868 * (DZ) ^ 3) + (-0.00329129114
* (DZ) ^ 4))
              End If

              DepotSafetyStock = (Dk * Sqr(DepotSLTD))
              DepotROP =
smutils_XL.WorksheetFunction.RoundUp((DepotSafetyStock + DepotMLTD), 0)

              g_SIMAN.VariableArrayValue(g_DepotReOrder) = DepotROP
              g_SIMAN.VariableArrayValue(g_DepotSS) = DepotSafetyStock
              g_SIMAN.VariableArrayValue(g_DepotOrderQuantity) =
DepotOrderQuantity
              g_SIMAN.VariableArrayValue(g_Depot) =
.tbxInitialDepotInventory

              g_SIMAN.VariableArrayValue(SS) = CRSafetyStock
              g_SIMAN.VariableArrayValue(g_ReorderPt) = ROP

              g_SIMAN.VariableArrayValue(g_PeriodReview) =
.tbxReviewPeriod
              g_SIMAN.VariableArrayValue(g_MaxInvLevel) =
(.tbxReviewPeriod * 1 / .tbxArrivalRate) + PRSafetyStock
              g_SIMAN.VariableArrayValue(g_partialQ) = PR_S
              g_SIMAN.VariableArrayValue(g_k) = CRgk
              g_SIMAN.VariableArrayValue(g_ArrivalRate) =
.tbxArrivalRate
              g_SIMAN.VariableArrayValue(g_DepotLT) = (.tbxDepotLT)
              g_SIMAN.VariableArrayValue(g_SupplierLT) =
(.tbxSupplierLT)

              'Set the Continuous Review Reorder Whse Level

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse", 1)) = PR_S

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse", 4)) = ROP
* 2

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("OrderQuantity", 4)) =
CROrderQuantity
```

```
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse", 7)) = IROP
* 2

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("OrderQuantity", 7)) =
IROrderQuantity
              g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Depot"))
= DepotROP + 1

         End With

         'Print out the values of the starting parameter
         'Print out the values of the starting parameter
         If g_SIMAN.RunCurrentReplication = 1 Then

              With
smutils_XL.Workbooks(g_XLOutputFile).Worksheets("Sheet1")
              .Cells(2, 1).value = "PRMLTD"
              .Cells(3, 1).value = "PRSLTD"
              .Cells(4, 1).value = "PRSafetyStock"
              .Cells(5, 1).value = "PRgk"
              .Cells(6, 1).value = "PRk"
              .Cells(7, 1).value = "PR_S"
              .Cells(8, 1).value = "CRMLTD"
              .Cells(9, 1).value = "CRSLTD"
              .Cells(10, 1).value = "CRSafetyStock"
              .Cells(11, 1).value = "CRgk"
              .Cells(12, 1).value = "CRk"
              .Cells(13, 1).value = "ROP"
              .Cells(14, 1).value = "IRMLTD"
              .Cells(15, 1).value = "IRSLTD"
              .Cells(16, 1).value = "IRSafetyStock"
              .Cells(17, 1).value = "IRgk"
              .Cells(18, 1).value = "IRk"
              .Cells(19, 1).value = "IROP"
              .Cells(20, 1).value = "DepotMLTD"
              .Cells(21, 1).value = "DepotSLTD"
              .Cells(22, 1).value = "DepotSafetyStock"
              .Cells(23, 1).value = "Depotgk"
              .Cells(24, 1).value = "Depotk"
              .Cells(25, 1).value = "DepotROP"


              .Cells(2, 2).value = PRMLTD
              .Cells(3, 2).value = PRSLTD
              .Cells(4, 2).value = PRSafetyStock
              .Cells(5, 2).value = PRgk
              .Cells(6, 2).value = PRk
              .Cells(7, 2).value = PR_S
              .Cells(8, 2).value = CRMLTD
              .Cells(9, 2).value = CRSLTD
              .Cells(10, 2).value = CRSafetyStock
              .Cells(11, 2).value = CRgk
              .Cells(12, 2).value = CRk
```

```
                .Cells(13, 2).value = ROP
                .Cells(14, 2).value = IRMLTD
                .Cells(15, 2).value = IRSLTD
                .Cells(16, 2).value = IRSafetyStock
                .Cells(17, 2).value = IRgk
                .Cells(18, 2).value = IRk
                .Cells(19, 2).value = IROP
                .Cells(20, 2).value = DepotMLTD
                .Cells(21, 2).value = DepotSLTD
                .Cells(22, 2).value = DepotSafetyStock
                .Cells(23, 2).value = Dgk
                .Cells(24, 2).value = Dk
                .Cells(25, 2).value = DepotROP

                End With

        End If

                'Move the Column of Spreadsheet Data to the right, two
columns, for next replication
                'return the Row Markers to the second row (first row has the
labels)
            g_outputRow = 2
            g_TimeSystemRow = 2
        End Sub
        Private Sub ModelLogic_RunEndReplication()
        Dim CustOneOrders, CustTwoOrders, CustThreeOrders, DepotOrders As
Long
        Dim PFill1, PFill2, PFill3 As Double
        Dim Stockout1, Stockout2, Stockout3, Stockout4 As Long


        CustOneOrders = g_SIMAN.CounterValue(g_SIMAN.SymbolNumber("Cust
1_C"))
        CustTwoOrders = g_SIMAN.CounterValue(g_SIMAN.SymbolNumber("Cust
2_C"))
        CustThreeOrders = g_SIMAN.CounterValue(g_SIMAN.SymbolNumber("Cust
3_C"))
        DepotOrders =
g_SIMAN.CounterValue(g_SIMAN.SymbolNumber("DepotOrders"))

        Stockout1 =
g_SIMAN.CounterValue(g_SIMAN.SymbolNumber("PROutOfStock"))
        Stockout2 =
g_SIMAN.CounterValue(g_SIMAN.SymbolNumber("CROutOfStock"))
        Stockout3 =
g_SIMAN.CounterValue(g_SIMAN.SymbolNumber("JITOutOfStock"))
        Stockout4 =
g_SIMAN.CounterValue(g_SIMAN.SymbolNumber("DepotOutOfStock"))

        'PFill1 = 1 - (Stockout1 / CustOneOrders)
        PFill2 = 1 - (Stockout2 / CustTwoOrders)
        'PFill3 = 1 - (Stockout3 / CustThreeOrders)
```

```
      ' Write the data out to the next row of the output file:
      ' Total orders in column "A", current time into column "B"
        With smutils_XL.Workbooks(g_XLOutputFile).Worksheets("Sheet2")

          .Cells(g_CounterOutputRow, 1) = CustOneOrders
          .Cells(g_CounterOutputRow, 2) = Stockout1
          .Cells(g_CounterOutputRow, 3) = PFill1
          .Cells(g_CounterOutputRow, 4) = CustTwoOrders
          .Cells(g_CounterOutputRow, 5) = Stockout2
          .Cells(g_CounterOutputRow, 6) = PFill2
          .Cells(g_CounterOutputRow, 7) = CustThreeOrders
          .Cells(g_CounterOutputRow, 8) = Stockout3
          .Cells(g_CounterOutputRow, 9) = PFill3
          .Cells(g_CounterOutputRow, 10) = CustOneOrders +
CustTwoOrders + CustThreeOrders
          .Cells(g_CounterOutputRow, 11) = Stockout4
        End With

        With smutils_XL.Workbooks(g_XLOutputFile).Worksheets("Sheet4")
           .Cells(g_CounterOutputRow, 1).value =
g_SIMAN.TallyAverage(1)
           .Cells(g_CounterOutputRow, 2).value =
g_SIMAN.TallyStandardDeviation(1)
           .Cells(g_CounterOutputRow, 3).value =
g_SIMAN.TallyAverage(2)
           .Cells(g_CounterOutputRow, 4).value =
g_SIMAN.TallyStandardDeviation(2)
           .Cells(g_CounterOutputRow, 5).value =
g_SIMAN.TallyAverage(3)
           .Cells(g_CounterOutputRow, 6).value =
g_SIMAN.TallyStandardDeviation(3)

        End With

          ' Increment the output counter
          g_CounterOutputRow = g_CounterOutputRow + 1
          g_OutputCol = g_OutputCol + 3

        End Sub
        Private Sub VBA_Block_1_Fire()

        'Compute the total time in the system for an entity
        'If there was no stock out then the total time is equal to
zero, else time is queue time plus order time

          Dim range As String
          Dim Customerbase As Long
          Dim TimeInSystem, test As Double
          Customerbase = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_CustBase)
          TimeInSystem = g_SIMAN.RunCurrentTime -
g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity, g_Enter)
        ' Write the data out to the next row of the output file:
          ' part number in column "A", current time into column "B"
```

```
            If TimeInSystem > 0 Then

            If Customerbase < 4 Then
            g_SIMAN.TallyRecordObservation 1, TimeInSystem
            ElseIf Customerbase < 7 Then
            g_SIMAN.TallyRecordObservation 2, TimeInSystem
            Else
            g_SIMAN.TallyRecordObservation 3, TimeInSystem

            End If
            ' Increment the output counter
            'g_TimeSystemRow = g_TimeSystemRow + 1
            End If
        End Sub
        Private Sub VBA_Block_2_Fire()
           'Delivers the order to the warehouse
           ' Get the part number from the attribute of the current entity

            Dim Customerbase, Whse, OnOrder, OrderQuantity,
PROrderQuantity, BackOrdered As Long

            'Assign Attributes
            Customerbase = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_CustBase)
            PROrderQuantity =
g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_SIMAN.SymbolNumber("PROrderQuantity"))

            'Assign Variables
            Whse =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase))
            OnOrder =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("OnOrder",
Customerbase))
            BackOrdered =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Backordered",
Customerbase))
            OrderQuantity =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("OrderQuantity",
Customerbase))

            'Reduce the counter for quantity on order and
            'Increase the counter for quantity in the warehouse
        If Customerbase < 4 Then

            g_SIMAN.CounterRecordObservation
(g_SIMAN.SymbolNumber("NumberofOrders")), 1
            g_SIMAN.CounterRecordObservation
(g_SIMAN.SymbolNumber("UnitsOrdered")), PROrderQuantity
            g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("OnOrder",
Customerbase)) = (OnOrder - PROrderQuantity)
            g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase)) = Whse + PROrderQuantity
```

```
            Whse =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase))
            If (Whse - BackOrdered) >= 1 Then

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase)) = Whse - BackOrdered

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Backordered",
Customerbase)) = 0

            Else

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase)) = 0

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Backordered",
Customerbase)) = BackOrdered - PROrderQuantity
            End If

        Else

            g_SIMAN.CounterRecordObservation
(g_SIMAN.SymbolNumber("NumberofOrders")), 1
            g_SIMAN.CounterRecordObservation
(g_SIMAN.SymbolNumber("UnitsOrdered")), OrderQuantity
            g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("OnOrder",
Customerbase)) = (OnOrder - OrderQuantity)
            g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase)) = Whse + OrderQuantity
            Whse =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase))
            If (Whse - BackOrdered) >= 1 Then

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase)) = Whse - BackOrdered

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Backordered",
Customerbase)) = 0

            Else

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase)) = 0

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Backordered",
Customerbase)) = BackOrdered - OrderQuantity
            End If
        End If


        End Sub
        ' End of run cleanup
```

```
Private Sub ModelLogic_RunEndSimulation()
Dim OldFile, NewFile, Path As String

    ' Save the output file and close Excel
    With smutils_XL.Workbooks(g_XLOutputFile)
    .Worksheets(1).Name = "Setup Parameters"
    .Worksheets(2).Name = "Stockouts"
    .Worksheets(3).Name = "Runtime In System"
    .Worksheets(4).Name = "Avg LT and Std Dev"
    End With

    smutils_SaveExcelWorkbook g_XLOutputFile, g_ArenaDir & "Run_"
& ServiceLevel & "_" & ModelSetup.tbxArrivalRate & "_" &
ModelSetup.tbxDepotLT & "_" & ModelSetup.tbxSupplierLT & "_" &
ModelSetup.tbxRunlength & "_" & ModelSetup.tbxReplicat & "_CR.xls"
    smutils_ExitExcel

    ' Return to model view
    Dim viewIndex As Long
    With g_Model
        viewIndex = .NamedViews.Find(smFindName, "Overview")
        If viewIndex > 0 Then .ActiveView.ZoomView
.NamedViews.Item(viewIndex)
    End With


    Path = "Run_" & ServiceLevel & "_" &
ModelSetup.tbxArrivalRate & "_" & ModelSetup.tbxDepotLT & "_" &
ModelSetup.tbxSupplierLT & "_" & ModelSetup.tbxRunlength & "_" &
ModelSetup.tbxReplicat & "_CR"

        MkDir Path


    OldFile = Dir("*.dat")
    Path = "Run_" & ServiceLevel & "_" &
ModelSetup.tbxArrivalRate & "_" & ModelSetup.tbxDepotLT & "_" &
ModelSetup.tbxSupplierLT & "_" & ModelSetup.tbxRunlength & "_" &
ModelSetup.tbxReplicat & "_CR"

    Do While OldFile <> ""

    FileCopy OldFile, Path & "/" & OldFile
    OldFile = Dir$
    Loop

    OldFile = Dir("*.out")

    Do While OldFile <> ""

    FileCopy OldFile, Path & "/" & OldFile
    OldFile = Dir$
    Loop
```

```
      End Sub

      Private Sub VBA_Block_4_Fire()
          Dim Customerbase, Whse, Order, OnOrder, OrderQuantity,
BackOrdered, CurrentEntity As Long

          'Assign Attributes
          Customerbase = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_CustBase)

          'Assign Variables
          Whse =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase))
          BackOrdered =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("BackOrdered",
Customerbase))
          OnOrder =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("OnOrder",
Customerbase))
          CurrentEntity = g_SIMAN.ActiveEntity
        If Customerbase < 4 Then
              If Whse < 1 Then
                  g_SIMAN.CounterRecordObservation
g_SIMAN.SymbolNumber("PROutOfstock"), 1

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("BackOrdered",
Customerbase)) = BackOrdered + 1
                  g_SIMAN.EntityDispose CurrentEntity
              Else
                  g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity,
0, "Warehouse"
              End If
        Else
          If Customerbase < 7 Then
              If Whse < 1 Then
                  g_SIMAN.CounterRecordObservation
g_SIMAN.SymbolNumber("CROutOfstock"), 1

g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("BackOrdered",
Customerbase)) = BackOrdered + 1
                  g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity,
0, "PointOfSale"

              Else
                  g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity,
0, "Warehouse"
              End If
          Else
              If Whse < 1 Then
                  g_SIMAN.CounterRecordObservation
g_SIMAN.SymbolNumber("JITOutOfstock"), 1
```

```
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("BackOrdered",
Customerbase)) = BackOrdered + 1
                  g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity,
0, "PointOfSale"
              Else
                  g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity,
0, "Warehouse"
              End If
          End If
        End If
      End Sub

      Private Sub VBA_Block_5_Fire()
      Dim Depot, DepotOutOfStock As Long
      Dim OrderQuantity, PROrderQuantity As Long
      Dim Customerbase As Long

      Customerbase = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_CustBase)
      PROrderQuantity = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_SIMAN.SymbolNumber("PROrderQuantity"))
      'DepotOutOfStock =
g_SIMAN.CounterValue(g_SIMAN.SymbolNumber("DepotOutOfStock"))
      Depot = g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Depot"))
      OrderQuantity =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("OrderQuantity",
Customerbase))


      If Customerbase < 4 Then
          If Depot < PROrderQuantity Then
              g_SIMAN.CounterRecordObservation
g_SIMAN.SymbolNumber("DepotOutOfStock"), PROrderQuantity
              g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity, 0,
"PRDepotQ"
          Else
              g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity, 0,
"DepotFill"
          End If
      Else

              g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_SIMAN.SymbolNumber("PROrderQuantity")) = OrderQuantity
              PROrderQuantity =
g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_SIMAN.SymbolNumber("PROrderQuantity"))
          If Depot < PROrderQuantity Then
              g_SIMAN.CounterRecordObservation
g_SIMAN.SymbolNumber("DepotOutOfStock"), 1
              g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity, 0,
"PRDepotQ"
          Else
```

```
            g_SIMAN.EntitySendToBlockLabel
g_SIMAN.ActiveEntity, 0, "DepotFill"

        End If
    End If

    End Sub

    Private Sub VBA_Block_6_Fire()
        Dim Customerbase, Whse, Order, OnOrder, OrderQuantity,
BackOrdered, CurrentEntity As Long

        'Assign Attributes
        Customerbase = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_CustBase)

        'Assign Variables
        Whse =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase))
        BackOrdered =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("BackOrdered",
Customerbase))
        OnOrder =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("OnOrder",
Customerbase))
        CurrentEntity = g_SIMAN.ActiveEntity


        If Customerbase < 7 Then
                If Whse + OnOrder - BackOrdered <= ROP Then
                    g_SIMAN.EntitySendToBlockLabel
g_SIMAN.ActiveEntity, 0, "MakeOrder"
                Else
                    g_SIMAN.EntitySendToBlockLabel
g_SIMAN.ActiveEntity, 0, "Consume2"
                End If

        Else
                If Whse + OnOrder - BackOrdered <= IROP Then
                    g_SIMAN.EntitySendToBlockLabel
g_SIMAN.ActiveEntity, 0, "MakeOrder"
                Else
                    g_SIMAN.EntitySendToBlockLabel
g_SIMAN.ActiveEntity, 0, "Consume2"
                End If

        End If
    End Sub

    Private Sub VBA_Block_7_Fire()
        'Periodic Review Routine
       ' Get the part number from the attribute of the current entity
```

```
          Dim Customerbase, Whse, Order, OrderQuantity,
PROrderQuantity, BackOrdered As Long

          'Assign Attributes
          Customerbase = g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_CustBase)
          PROrderQuantity =
g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_SIMAN.SymbolNumber("PROrderQuantity"))

          'Assign Variables
          Whse =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("Warehouse",
Customerbase))
          Order =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("OnOrder",
Customerbase))
          BackOrdered =
g_SIMAN.VariableArrayValue(g_SIMAN.SymbolNumber("BackOrdered",
Customerbase))

          'Determine if the Potential Order quantity is greater than
what is on hand and on order and
          'if it is, then order the difference between max order size,
and what is on-hand

          If PR_S + BackOrdered >= Whse + Order Then
              g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_SIMAN.SymbolNumber("PROrderQuantity")) = (PR_S + BackOrdered) - (Whse
+ Order)
              If g_SIMAN.EntityAttribute(g_SIMAN.ActiveEntity,
g_SIMAN.SymbolNumber("PROrderQuantity")) = 0 Then
                  g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity,
0, "Consume2"
              Else
                  g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity,
0, "PRMakeOrder"
              End If
          Else
              g_SIMAN.EntitySendToBlockLabel g_SIMAN.ActiveEntity, 0,
"Consume2"

          End If

      End Sub
```

Appendix D

SIMULATION FLOW DIAGRAMS

Continuous Review policy

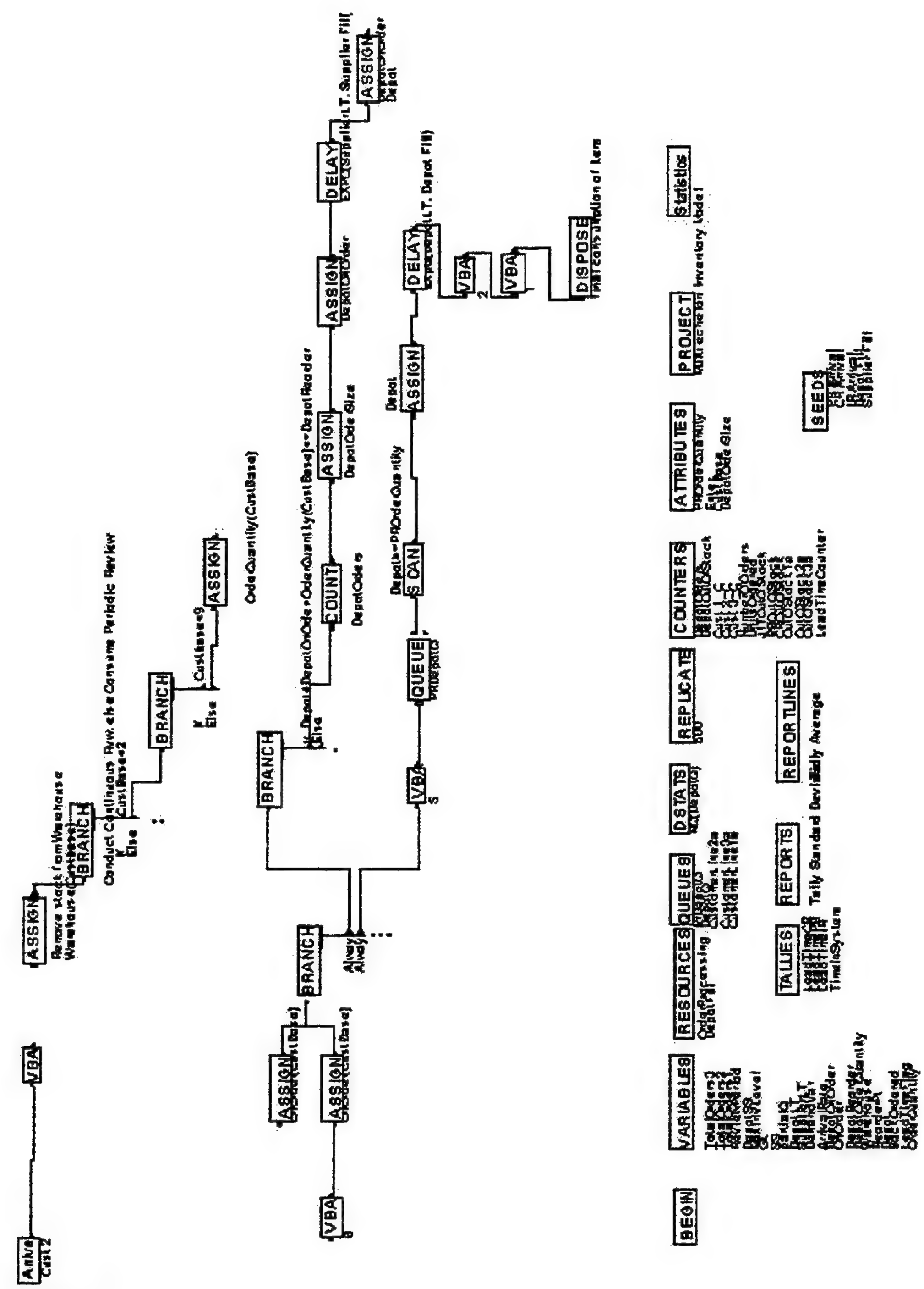

Figure 9-1

Periodic Review Policy

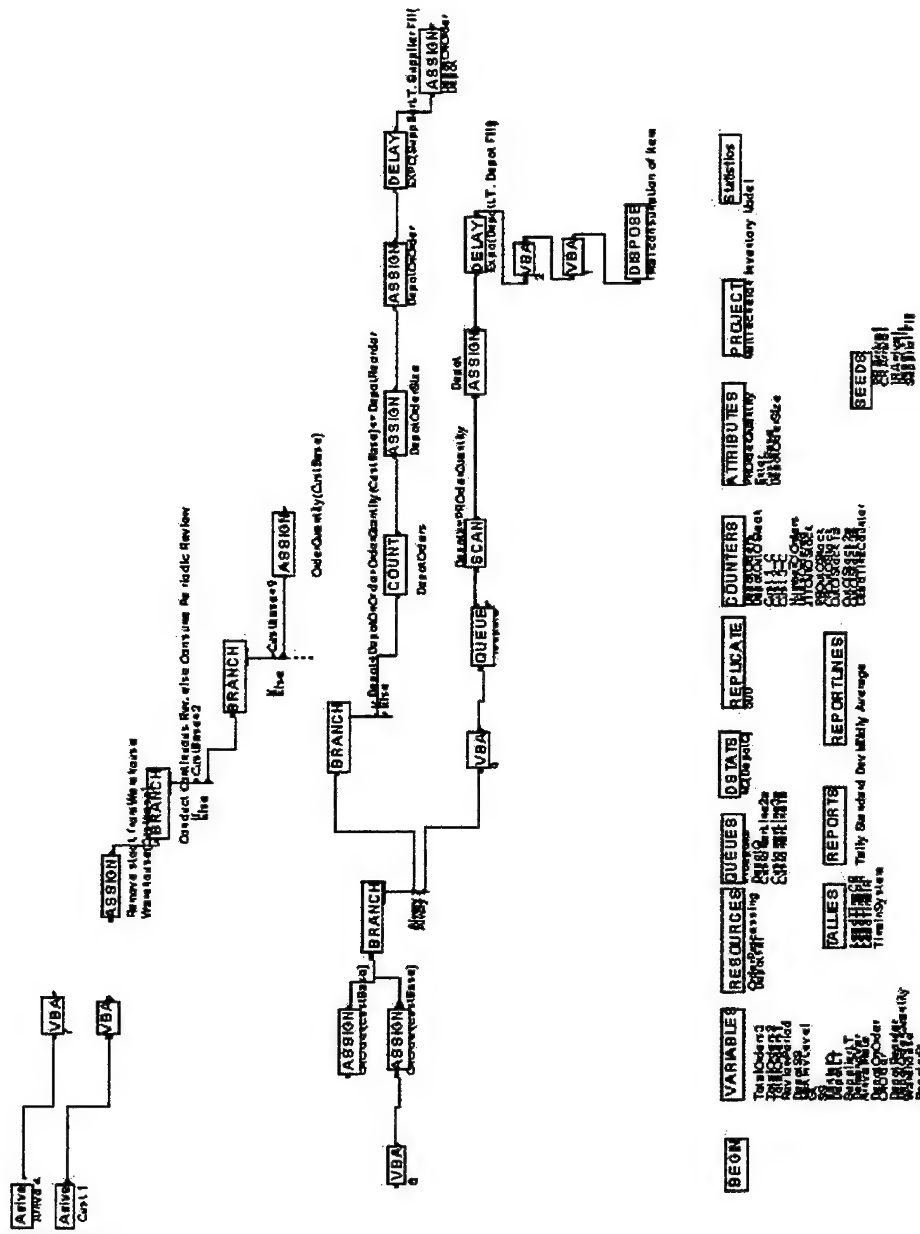

Figure 9-2

Instantaneous Reorder Policy

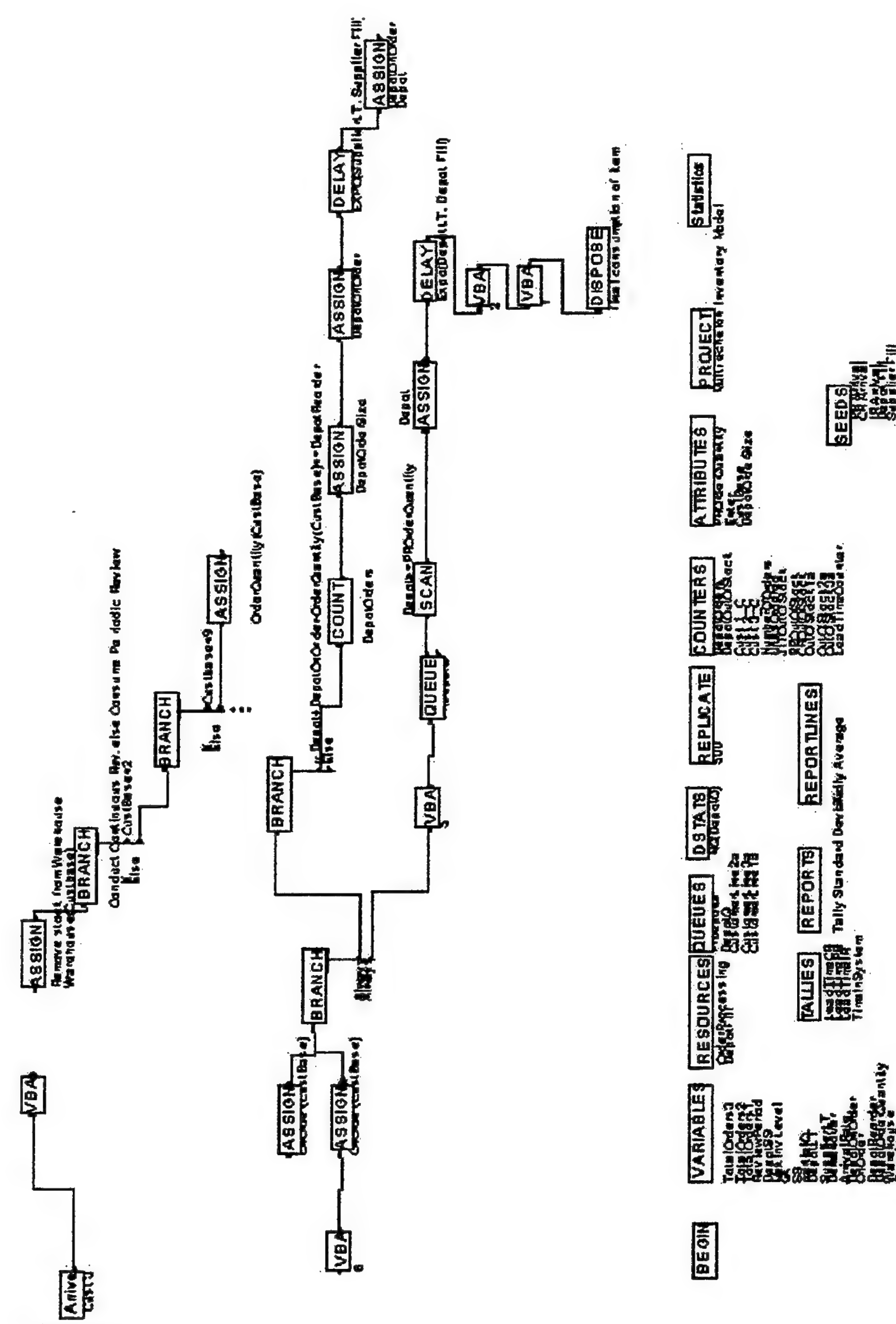

Figure 9-3

FULL MODEL

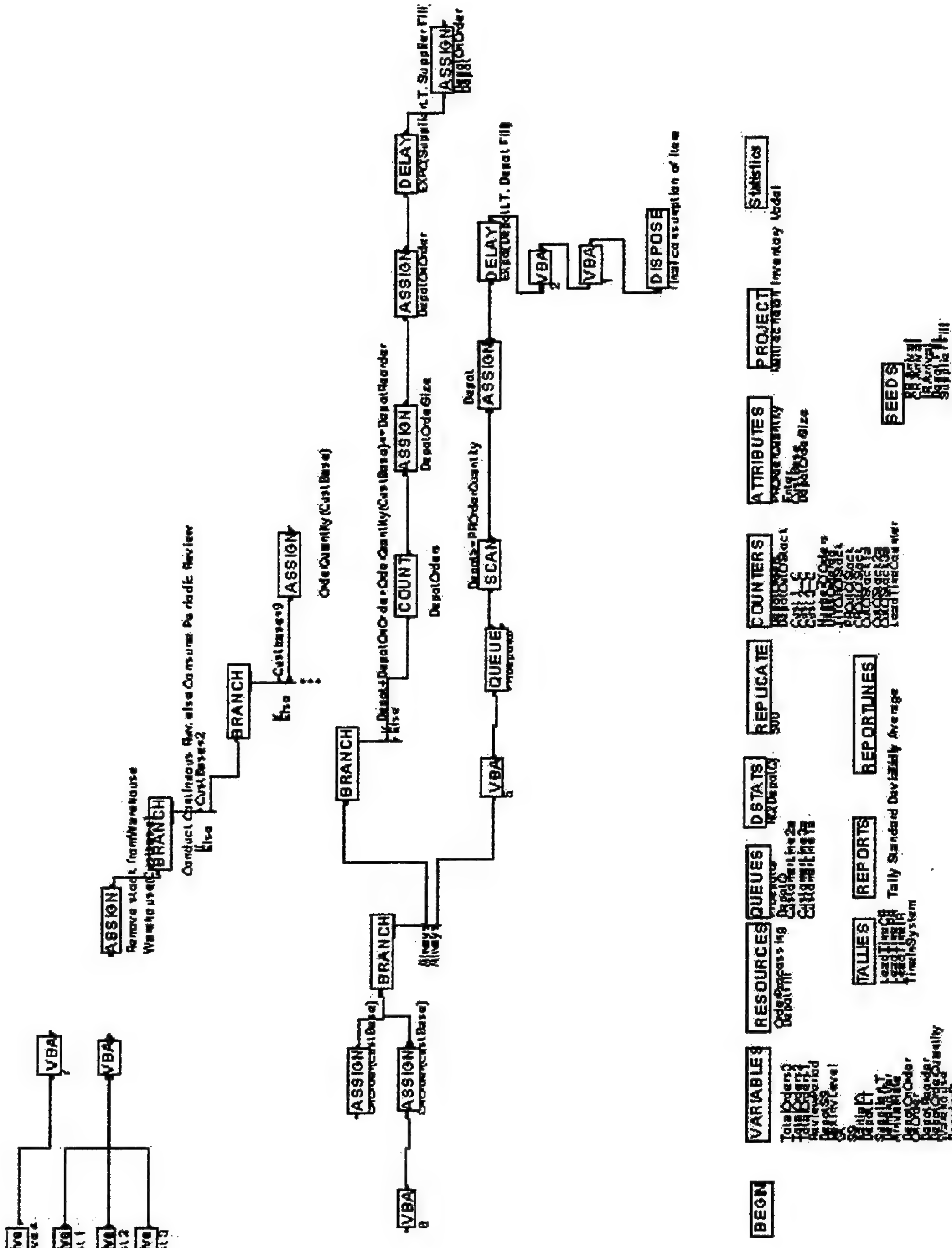

Figure 9-4

Appendix E

ANOVA RESULTS

ANOVA RESULTS: 98 Percent Service, 20 Inter-Arrival Time
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.186	0.972867	0.000404
Column 2	30	29.30273	0.976758	0.000203
Column 3	30	29.38742	0.979581	0.000162

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000682	2	0.000341	1.33006	0.269785	3.101292
Within Groups	0.022302	87	0.000256			
Total	0.022983	89				

ANOVA RESULTS: 98 Percent Service, 19 Inter-Arrival Time
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.08742	0.969581	0.000331
Column 2	30	29.6226	0.98742	0.00011
Column 3	30	29.19211	0.97307	0.000174

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.005363	2	0.002682	13.08456	1.08E-05	3.101292
Within Groups	0.017831	87	0.000205			
Total	0.023194	89				

ANOVA RESULTS: 98 Percent Service, 18 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	28.83151	0.96105	0.000641
Column 2	30	29.4117	0.98039	0.000168
Column 3	30	29.1426	0.97142	0.000193

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00562	2	0.00281	8.411579	0.000457	3.101292
Within Groups	0.029065	87	0.000334			
Total	0.034685	89				

ANOVA RESULTS: 98 Percent Service, 17 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	28.62483	0.954161	0.000463
Column 2	30	29.36011	0.97867	0.000144
Column 3	30	28.94595	0.964865	0.000261

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.009059	2	0.004529	15.63894	1.58E-06	3.101292
Within Groups	0.025197	87	0.00029			
Total	0.034256	89				

ANOVA RESULTS: 98 Percent Service, 16 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.3057	0.976857	0.000313
Column 2	30	29.38438	0.979479	0.000185
Column 3	30	29.70099	0.990033	4.18E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.002919	2	0.001459	8.121032	0.000584	3.101292
Within Groups	0.015634	87	0.00018			
Total	0.018553	89				

ANOVA RESULTS: 98 Percent Service, 15 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.14858	0.971619	0.000277
Column 2	30	29.2841	0.976137	0.00022
Column 3	30	29.63531	0.987844	0.000147

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004207	2	0.002103	9.80017	0.000145	3.101292
Within Groups	0.018673	87	0.000215			
Total	0.02288	89				

ANOVA RESULTS: 98 Percent Service, 14 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.01984	0.967328	0.00025
Column 2	30	29.47569	0.982523	0.00011
Column 3	30	29.52041	0.984014	9.1E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.005115	2	0.002558	17.02237	5.77E-07	3.101292
Within Groups	0.013072	87	0.00015			
Total	0.018187	89				

ANOVA RESULTS: 98 Percent Service, 13 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.40847	0.980282	0.000215
Column 2	30	29.40993	0.980331	0.000186
Column 3	30	29.4263	0.980877	0.000129

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6.53E-06	2	3.27E-06	0.018513	0.981661	3.101292
Within Groups	0.015349	87	0.000176			
Total	0.015355	89				

ANOVA RESULTS: 98 Percent Service, 12 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.16318	0.972106	0.000129
Column 2	30	29.18892	0.972964	0.000176
Column 3	30	29.22105	0.974035	0.000196

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.6E-05	2	2.8E-05	0.1677	0.84588	3.101292
Within Groups	0.014535	87	0.000167			
Total	0.014591	89				

ANOVA RESULTS: 98 Percent Service, 11 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.4832	0.982773	0.00015
Column 2	30	29.40566	0.980189	0.000185
Column 3	30	29.72357	0.990786	4.17E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001832	2	0.000916	7.287904	0.001185	3.101292
Within Groups	0.010934	87	0.000126			
Total	0.012766	89				

ANOVA RESULTS: 98 Percent Service, 10 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.11899	0.970633	0.000279
Column 2	30	29.26213	0.975404	0.000167
Column 3	30	29.59872	0.986624	6.97E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004044	2	0.002022	11.75539	3.03E-05	3.101292
Within Groups	0.014963	87	0.000172			
Total	0.019006	89				

ANOVA RESULTS: 98 Percent Service, 9 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.34019	0.978006	0.000211
Column 2	30	29.37232	0.979077	0.000184
Column 3	30	29.24808	0.974936	0.000191

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000277	2	0.000139	0.709579	0.494675	3.101292
Within Groups	0.016996	87	0.000195			
Total	0.017273	89				

ANOVA RESULTS: 98 Percent Service, 8 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.40619	0.980206	0.000161
Column 2	30	29.2485	0.97495	0.000183
Column 3	30	29.55939	0.985313	0.000122

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001611	2	0.000805	5.19263	0.007407	3.101292
Within Groups	0.013496	87	0.000155			
Total	0.015107	89				

ANOVA RESULTS: 98 Percent Service, 7 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.38469	0.97949	0.000182
Column 2	30	29.10557	0.970186	0.000262
Column 3	30	29.15952	0.971984	0.000136

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001461	2	0.000731	3.7807	0.02664	3.101292
Within Groups	0.016814	87	0.000193			
Total	0.018275	89				

ANOVA RESULTS: 98 Percent Service, 6 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.7001	0.990003	7.71E-05
Column 2	30	29.41145	0.980382	0.000157
Column 3	30	29.40572	0.980191	8.94E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001889	2	0.000944	8.765621	0.00034	3.101292
Within Groups	0.009374	87	0.000108			
Total	0.011263	89				

ANOVA RESULTS: 98 Percent Service, 5 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.65689	0.988563	9.7E-05
Column 2	30	29.34168	0.978056	0.000106
Column 3	30	29.32413	0.977471	0.000151

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002338	2	0.001169	9.917921	0.000132	3.101292
Within Groups	0.010254	87	0.000118			
Total	0.012591	89				

ANOVA RESULTS: 98 Percent Service, 4 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.73159	0.991053	5.08E-05
Column 2	30	29.47643	0.982548	8.06E-05
Column 3	30	29.55578	0.985193	6.28E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001137	2	0.000568	8.782766	0.000335	3.101292
Within Groups	0.00563	87	6.47E-05			
Total	0.006767	89				

ANOVA RESULTS: 98 Percent Service, 3 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.85111	0.995037	1.3E-05
Column 2	30	29.66686	0.988895	5.41E-05
Column 3	30	29.41277	0.980426	8.12E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.003229	2	0.001615	32.65546	2.63E-11	3.101292
Within Groups	0.004302	87	4.94E-05			
Total	0.007531	89				

ANOVA RESULTS: 98 Percent Service, 2 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.9027	0.996757	1.18E-05
Column 2	30	29.89221	0.996407	9.47E-06
Column 3	30	29.57154	0.985718	5.27E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002362	2	0.001181	47.91991	9.31E-15	3.101292
Within Groups	0.002144	87	2.46E-05			
Total	0.004507	89				

ANOVA RESULTS: 98 Percent Service, 1 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.95499	0.9985	2.78E-06
Column 2	30	29.99801	0.999934	7.45E-08
Column 3	30	29.63223	0.987741	3.78E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002665	2	0.001332	98.3037	4.74E-23	3.101292
Within Groups	0.001179	87	1.36E-05			
Total	0.003844	89				

ANOVA RESULTS: 95 Percent Service, 20 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.7708	0.925693	0.000878
Column 2	30	29.29878	0.976626	0.000209
Column 3	30	29.37942	0.979314	0.000167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.054765	2	0.027383	65.54417	4.35E-18	3.101292
Within Groups	0.036346	87	0.000418			
Total	0.091112	89				

ANOVA RESULTS: 95 Percent Service, 19 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.57014	0.919005	0.000778
Column 2	30	29.18056	0.972685	0.000298
Column 3	30	29.20619	0.97354	0.000182

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.058564	2	0.029282	69.85468	8.06E-19	3.101292
Within Groups	0.036469	87	0.000419			
Total	0.095033	89				

ANOVA RESULTS: 95 Percent Service, 18 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.81085	0.960362	0.000587
Column 2	30	28.73746	0.957915	0.000558
Column 3	30	29.13229	0.971076	0.000168

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00294	2	0.00147	3.35791	0.039375	3.101292
Within Groups	0.038087	87	0.000438			
Total	0.041027	89				

ANOVA RESULTS: 95 Percent Service, 17 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.61806	0.953935	0.000462
Column 2	30	28.88984	0.962995	0.000376
Column 3	30	28.93806	0.964602	0.000243

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001984	2	0.000992	2.753327	0.069273	3.101292
Within Groups	0.031349	87	0.00036			
Total	0.033333	89				

ANOVA RESULTS: 95 Percent Service, 16 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	28.24209	0.941403	0.000549
Column 2	30	28.97785	0.965928	0.000203
Column 3	30	28.80433	0.960144	0.000241

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.009862	2	0.004931	14.90795	2.71E-06	3.101292
Within Groups	0.028776	87	0.000331			
Total	0.038638	89				

ANOVA RESULTS: 95 Percent Service, 15 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	27.98806	0.932935	0.000677
Column 2	30	28.80803	0.960268	0.00026
Column 3	30	28.46621	0.948874	0.000468

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.011309	2	0.005654	12.07155	2.36E-05	3.101292
Within Groups	0.040752	87	0.000468			
Total	0.052061	89				

ANOVA RESULTS: 95 Percent Service, 14 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.85571	0.961857	0.000671
Column 2	30	28.44259	0.948086	0.0004
Column 3	30	28.25763	0.941921	0.000401

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.006251	2	0.003125	6.373149	0.002613	3.101292
Within Groups	0.042665	87	0.00049			
Total	0.048916	89				

ANOVA RESULTS: 95 Percent Service, 13 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.72525	0.957508	0.000456
Column 2	30	29.00929	0.966976	0.000173
Column 3	30	29.47318	0.982439	0.000157

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.009503	2	0.004752	18.14528	2.59E-07	3.101292
Within Groups	0.022782	87	0.000262			
Total	0.032285	89				

ANOVA RESULTS: 95 Percent Service, 12 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.19397	0.939799	0.000381
Column 2	30	28.87132	0.962377	0.000226
Column 3	30	29.1951	0.97317	0.000213

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.017399	2	0.0087	31.81182	4.27E-11	3.101292
Within Groups	0.023792	87	0.000273			
Total	0.041191	89				

ANOVA RESULTS: 95 Percent Service, 11 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.74493	0.958164	0.000268
Column 2	30	28.58906	0.952969	0.000301
Column 3	30	28.93586	0.964529	0.000205

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.002011	2	0.001006	3.894868	0.023987	3.101292
Within Groups	0.022464	87	0.000258			
Total	0.024475	89				

ANOVA RESULTS: 95 Percent Service, 10 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.44938	0.948313	0.000343
Column 2	30	28.87571	0.962524	0.00034
Column 3	30	28.66537	0.955512	0.00028

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.003029	2	0.001515	4.72119	0.011309	3.101292
Within Groups	0.027912	87	0.000321			
Total	0.030942	89				

ANOVA RESULTS: 95 Percent Service, 9 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.75983	0.958661	0.000408
Column 2	30	28.50318	0.950106	0.000511
Column 3	30	29.2605	0.97535	0.000188

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00989	2	0.004945	13.39753	8.47E-06	3.101292
Within Groups	0.03211	87	0.000369			
Total	0.042	89				

ANOVA RESULTS: 95 Percent Service, 8 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.88043	0.962681	0.000363
Column 2	30	28.73498	0.957833	0.000219
Column 3	30	28.67299	0.955766	0.000303

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.000756	2	0.000378	1.281425	0.282829	3.101292
Within Groups	0.025658	87	0.000295			
Total	0.026414	89				

ANOVA RESULTS: 95 Percent Service, 7 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.94413	0.964804	0.000222
Column 2	30	28.68703	0.956234	0.000341
Column 3	30	29.13344	0.971115	0.000134

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.003347	2	0.001673	7.202886	0.001275	3.101292
Within Groups	0.020212	87	0.000232			
Total	0.023559	89				

ANOVA RESULTS: 95 Percent Service, 6 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.95963	0.965321	0.000265
Column 2	30	28.72101	0.957367	0.000252
Column 3	30	28.31326	0.943775	0.0003

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.007122	2	0.003561	13.08758	1.07E-05	3.101292
Within Groups	0.023672	87	0.000272			
Total	0.030795	89				

ANOVA RESULTS: 95 Percent Service, 5 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.02919	0.96764	0.000161
Column 2	30	28.37149	0.945716	0.000418
Column 3	30	28.39435	0.946478	0.00039

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00929	2	0.004645	14.38967	3.99E-06	3.101292
Within Groups	0.028084	87	0.000323			
Total	0.037375	89				

ANOVA RESULTS: 95 Percent Service, 4 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.4954	0.98318	9.24E-05
Column 2	30	28.92034	0.964011	0.000464
Column 3	30	28.98487	0.966162	0.000138

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.006617	2	0.003308	14.29893	4.27E-06	3.101292
Within Groups	0.02013	87	0.000231			
Total	0.026746	89				

ANOVA RESULTS: 95 Percent Service, 3 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.55894	0.985298	6.55E-05
Column 2	30	29.26612	0.975537	8.75E-05
Column 3	30	28.76399	0.9588	0.000153

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.010776	2	0.005388	52.78419	9.76E-16	3.101292
Within Groups	0.00888	87	0.000102			
Total	0.019656	89				

ANOVA RESULTS: 95 Percent Service, 2 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.60467	0.986822	4.25E-05
Column 2	30	29.58811	0.98627	6.06E-05
Column 3	30	29.19449	0.97315	8.72E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.003594	2	0.001797	28.3233	3.36E-10	3.101292
Within Groups	0.00552	87	6.34E-05			
Total	0.009114	89				

ANOVA RESULTS: 95 Percent Service, 1 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	29.76151	0.99205	2.03E-05
Column 2	30	29.97285	0.999095	1.64E-06
Column 3	30	29.00611	0.96687	9.3E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.017221	2	0.00861	224.7594	4.29E-35	3.101292
Within Groups	0.003333	87	3.83E-05			
Total	0.020554	89				

ANOVA RESULTS: 92 Percent Service, 20 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.71868	0.923956	0.000844
Column 2	30	28.46808	0.948936	0.000589
Column 3	30	29.33568	0.977856	0.000208

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.043656	2	0.021828	39.89098	5.08E-13	3.101292
Within Groups	0.047605	87	0.000547			
Total	0.091261	89				

ANOVA RESULTS: 92 Percent Service, 19 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.49624	0.916541	0.000639
Column 2	30	28.44153	0.948051	0.00044
Column 3	30	29.21562	0.973854	0.000202

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.049433	2	0.024717	57.87273	1.04E-16	3.101292
Within Groups	0.037157	87	0.000427			
Total	0.08659	89				

ANOVA RESULTS: 92 Percent Service, 18 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.13423	0.904474	0.000932
Column 2	30	28.12293	0.937431	0.000592
Column 3	30	29.12654	0.970885	0.000144

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.066156	2	0.033078	59.48499	5.23E-17	3.101292
Within Groups	0.048379	87	0.000556			
Total	0.114535	89				

ANOVA RESULTS: 92 Percent Service, 17 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	26.75077	0.891692	0.000909
Column 2	30	28.03031	0.934344	0.000655
Column 3	30	28.94314	0.964771	0.000271

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.080855	2	0.040427	66.08359	3.51E-18	3.101292
Within Groups	0.053223	87	0.000612			
Total	0.134078	89				

ANOVA RESULTS: 92 Percent Service, 16 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.23913	0.941304	0.000555
Column 2	30	28.97157	0.965719	0.000204
Column 3	30	28.77818	0.959273	0.000283

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.009605	2	0.004803	13.81642	6.15E-06	3.101292
Within Groups	0.030241	87	0.000348			
Total	0.039846	89				

ANOVA RESULTS: 92 Percent Service, 15 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.98486	0.932829	0.000679
Column 2	30	28.80803	0.960268	0.00026
Column 3	30	28.45007	0.948336	0.00046

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.011357	2	0.005679	12.17775	2.17E-05	3.101292
Within Groups	0.04057	87	0.000466			
Total	0.051927	89				

ANOVA RESULTS: 92 Percent Service, 14 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	27.5373	0.91791	0.001171
Column 2	30	28.43672	0.947891	0.000395
Column 3	30	28.25096	0.941699	0.000401

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.015031	2	0.007515	11.46429	3.81E-05	3.101292
Within Groups	0.057033	87	0.000656			
Total	0.072064	89				

ANOVA RESULTS: 92 Percent Service, 13 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	27.14952	0.904984	0.000951
Column 2	30	28.29872	0.943291	0.000341
Column 3	30	27.91483	0.930494	0.000659

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.022819	2	0.01141	17.54157	3.98E-07	3.101292
Within Groups	0.056588	87	0.00065			
Total	0.079407	89				

ANOVA RESULTS: 92 Percent Service, 12 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.16107	0.938702	0.000537
Column 2	30	28.15494	0.938498	0.000512
Column 3	30	29.23307	0.974436	0.000219

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.025684	2	0.012842	30.40238	9.72E-11	3.101292
Within Groups	0.036749	87	0.000422			
Total	0.062434	89				

ANOVA RESULTS: 92 Percent Service, 11 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.5931	0.91977	0.000564
Column 2	30	28.59117	0.953039	0.000302
Column 3	30	28.93586	0.964529	0.000205

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.032422	2	0.016211	45.41112	3.12E-14	3.101292
Within Groups	0.031057	87	0.000357			
Total	0.063479	89				

ANOVA RESULTS: 92 Percent Service, 10 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	28.41806	0.947269	0.000354
Column 2	30	28.2828	0.94276	0.000325
Column 3	30	28.64975	0.954992	0.000261

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002296	2	0.001148	3.663026	0.02969	3.101292
Within Groups	0.027263	87	0.000313			
Total	0.029559	89				

ANOVA RESULTS: 92 Percent Service, 9 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	27.64233	0.921411	0.000522
Column 2	30	27.91803	0.930601	0.000583
Column 3	30	27.83646	0.927882	0.000531

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001337	2	0.000669	1.226035	0.298473	3.101292
Within Groups	0.047443	87	0.000545			
Total	0.04878	89				

ANOVA RESULTS: 92 Percent Service, 8 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	27.97365	0.932455	0.000574
Column 2	30	28.12928	0.937643	0.000481
Column 3	30	28.71288	0.957096	0.000259

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.010125	2	0.005063	11.55783	3.54E-05	3.101292
Within Groups	0.038108	87	0.000438			
Total	0.048234	89				

ANOVA RESULTS: 92 Percent Service, 7 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	28.37673	0.945891	0.000444
Column 2	30	28.21167	0.940389	0.000353
Column 3	30	27.7735	0.925783	0.000456

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.006479	2	0.00324	7.756686	0.000795	3.101292
Within Groups	0.036335	87	0.000418			
Total	0.042815	89				

ANOVA RESULTS: 92 Percent Service, 6 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	28.93096	0.964365	0.000257
Column 2	30	28.17219	0.939073	0.000199
Column 3	30	28.34876	0.944959	0.000261

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.01051	2	0.005255	21.99199	1.86E-08	3.101292
Within Groups	0.020788	87	0.000239			
Total	0.031297	89				

ANOVA RESULTS: 92 Percent Service, 5 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	28.44896	0.948299	0.000284
Column 2	30	28.09434	0.936478	0.000353
Column 3	30	28.44813	0.948271	0.000359

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002788	2	0.001394	4.199749	0.018148	3.101292
Within Groups	0.028878	87	0.000332			
Total	0.031667	89				

ANOVA RESULTS: 92 Percent Service, 4 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.73942	0.957981	0.000252
Column 2	30	28.04932	0.934977	0.00044
Column 3	30	27.87435	0.929145	0.000315

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.013947	2	0.006973	20.77989	4.2E-08	3.101292
Within Groups	0.029196	87	0.000336			
Total	0.043142	89				

ANOVA RESULTS: 92 Percent Service, 3 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.07399	0.969133	0.000206
Column 2	30	28.65329	0.95511	0.000224
Column 3	30	28.7388	0.95796	0.000148

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.003296	2	0.001648	8.564456	0.000402	3.101292
Within Groups	0.016742	87	0.000192			
Total	0.020038	89				

ANOVA RESULTS: 92 Percent Service, 2 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.11363	0.970454	0.000104
Column 2	30	29.25454	0.975151	8.39E-05
Column 3	30	28.59537	0.953179	0.000175

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.008033	2	0.004016	33.19403	1.94E-11	3.101292
Within Groups	0.010527	87	0.000121			
Total	0.018559	89				

ANOVA RESULTS: 92 Percent Service, 1 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	29.39344	0.979781	9.88E-05
Column 2	30	29.85977	0.995326	1.79E-05
Column 3	30	28.50137	0.950046	0.000147

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.031761	2	0.015881	180.7137	1.05E-31	3.101292
Within Groups	0.007645	87	8.79E-05			
Total	0.039406	89				

ANOVA RESULTS: 85 Percent Service, 20 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	24.4687	0.815623	0.001231
Column 2	30	26.60418	0.886806	0.000955
Column 3	30	27.23914	0.907971	0.000906

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.140431	2	0.070216	68.14222	1.56E-18	3.101292
Within Groups	0.089647	87	0.00103			
Total	0.230078	89				

ANOVA RESULTS: 85 Percent Service, 19 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.25528	0.908509	0.000833
Column 2	30	26.57274	0.885758	0.000775
Column 3	30	27.08757	0.902919	0.001176

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.008434	2	0.004217	4.543485	0.013279	3.101292
Within Groups	0.080745	87	0.000928			
Total	0.089178	89				

ANOVA RESULTS: 85 Percent Service, 18 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.23655	0.907885	0.000521
Column 2	30	26.21904	0.873968	0.001068
Column 3	30	26.69829	0.889943	0.000621

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.017275	2	0.008637	11.72395	3.1E-05	3.101292
Within Groups	0.064096	87	0.000737			
Total	0.081371	89				

ANOVA RESULTS: 85 Percent Service, 17 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	26.76002	0.892001	0.000674
Column 2	30	26.36852	0.878951	0.000582
Column 3	30	26.29422	0.876474	0.00102

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004175	2	0.002088	2.751233	0.069409	3.101292
Within Groups	0.066015	87	0.000759			
Total	0.07019	89				

ANOVA RESULTS: 85 Percent Service, 16 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	26.23253	0.874418	0.001118
Column 2	30	26.19798	0.873266	0.000909
Column 3	30	25.72961	0.857654	0.001295

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.005261	2	0.002631	2.375231	0.098998	3.101292
Within Groups	0.096351	87	0.001107			
Total	0.101612	89				

ANOVA RESULTS: 85 Percent Service, 15 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	25.56456	0.852152	0.001317
Column 2	30	27.58039	0.919346	0.00093
Column 3	30	28.36885	0.945628	0.000516

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.139437	2	0.069718	75.72202	8.97E-20	3.101292
Within Groups	0.080102	87	0.000921			
Total	0.219539	89				

ANOVA RESULTS: 85 Percent Service, 14 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	27.50077	0.916692	0.001104
Column 2	30	27.64324	0.921441	0.000513
Column 3	30	28.18093	0.939364	0.000378

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.008578	2	0.004289	6.449963	0.002443	3.101292
Within Groups	0.057853	87	0.000665			
Total	0.066431	89				

ANOVA RESULTS: 85 Percent Service, 13 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	27.09523	0.903174	0.001019
Column 2	30	27.29985	0.909995	0.000554
Column 3	30	27.86767	0.928922	0.000665

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.010677	2	0.005339	7.157305	0.001325	3.101292
Within Groups	0.064893	87	0.000746			
Total	0.07557	89				

ANOVA RESULTS: 85 Percent Service, 12 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	26.59159	0.886386	0.000636
Column 2	30	26.88414	0.896138	0.000868
Column 3	30	27.53998	0.917999	0.000869

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.015724	2	0.007862	9.942913	0.000129	3.101292
Within Groups	0.068792	87	0.000791			
Total	0.084516	89				

ANOVA RESULTS: 85 Percent Service, 11 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.52825	0.917608	0.000513
Column 2	30	26.41265	0.880422	0.00073
Column 3	30	26.72355	0.890785	0.000972

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.022097	2	0.011049	14.96532	2.6E-06	3.101292
Within Groups	0.064231	87	0.000738			
Total	0.086328	89				

ANOVA RESULTS: 85 Percent Service, 10 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	26.97955	0.899318	0.000759
Column 2	30	27.05726	0.901909	0.000473
Column 3	30	28.5979	0.953263	0.000296

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.05554	2	0.02777	54.50586	4.52E-16	3.101292
Within Groups	0.044326	87	0.000509			
Total	0.099866	89				

ANOVA RESULTS: 85 Percent Service, 9 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.62935	0.920978	0.000532
Column 2	30	26.85588	0.895196	0.000933
Column 3	30	27.85566	0.928522	0.000478

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.018323	2	0.009161	14.13994	4.82E-06	3.101292
Within Groups	0.056368	87	0.000648			
Total	0.074691	89				

ANOVA RESULTS: 85 Percent Service, 8 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	26.60144	0.886715	0.000628
Column 2	30	26.09251	0.86975	0.000919
Column 3	30	26.78716	0.892905	0.000988

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.008623	2	0.004311	5.101534	0.008035	3.101292
Within Groups	0.073525	87	0.000845			
Total	0.082147	89				

ANOVA RESULTS: 85 Percent Service, 7 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	27.19792	0.906597	0.000908
Column 2	30	26.64276	0.888092	0.000601
Column 3	30	27.85965	0.928655	0.000454

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.024744	2	0.012372	18.90788	1.52E-07	3.101292
Within Groups	0.056926	87	0.000654			
Total	0.08167	89				

ANOVA RESULTS: 85 Percent Service, 6 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	26.97416	0.899139	0.000686
Column 2	30	26.37133	0.879044	0.001055
Column 3	30	26.39945	0.879982	0.000794

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.007717	2	0.003858	4.566655	0.013004	3.101292
Within Groups	0.073504	87	0.000845			
Total	0.081221	89				

ANOVA RESULTS: 85 Percent Service, 5 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	30	27.7457	0.924857	0.000645
Column 2	30	26.49934	0.883311	0.000799
Column 3	30	26.56462	0.885487	0.000992

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.032807	2	0.016403	20.2064	6.2E-08	3.101292
Within Groups	0.070626	87	0.000812			
Total	0.103432	89				

ANOVA RESULTS: 85 Percent Service, 4 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.28485	0.909495	0.000505
Column 2	30	26.80094	0.893365	0.000443
Column 3	30	27.88741	0.92958	0.00035

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.019752	2	0.009876	22.83323	1.07E-08	3.101292
Within Groups	0.03763	87	0.000433			
Total	0.057382	89				

ANOVA RESULTS: 85 Percent Service, 3 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	27.54272	0.918091	0.000422
Column 2	30	27.34861	0.91162	0.000591
Column 3	30	27.64966	0.921655	0.000303

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001553	2	0.000776	1.769357	0.17652	3.101292
Within Groups	0.038174	87	0.000439			
Total	0.039727	89				

ANOVA RESULTS: 85 Percent Service, 2 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.43787	0.947929	0.000357
Column 2	30	27.97693	0.932564	0.000353
Column 3	30	27.51269	0.91709	0.000313

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.014266	2	0.007133	20.90991	3.84E-08	3.101292
Within Groups	0.029679	87	0.000341			
Total	0.043945	89				

ANOVA RESULTS: 85 Percent Service, 1 Inter-Arrival Time

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	30	28.3059	0.94353	0.000194
Column 2	30	29.53256	0.984419	7.42E-05
Column 3	30	27.70373	0.923458	0.000271

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.05791	2	0.028955	161.0966	5.63E-30	3.101292
Within Groups	0.015637	87	0.00018			
Total	0.073547	89				

Appendix F

TEST OF MEANS BETWEEN INDEPENDENT AND FULL MODELS

98 Percent Service Level

Periodic Review					
Full Run		Independent Run		Test of	
Percent	Std Dev	Percent	Std Dev	z-Score	Differences
97.20%	2.01%	97.12%	1.86%	-0.26	Accept
96.96%	1.82%	96.74%	1.71%	-0.33	Accept
96.11%	2.53%	96.01%	2.10%	-0.11	Accept
95.42%	2.14%	95.06%	2.25%	-0.45	Accept
97.60%	1.77%	97.99%	1.22%	0.55	Accept
97.16%	1.66%	97.37%	1.27%	0.38	Accept
96.73%	1.58%	96.40%	1.42%	-0.61	Accept
98.03%	1.47%	98.07%	1.16%	0.09	Accept
97.21%	1.14%	97.18%	1.28%	-0.07	Accept
98.28%	1.23%	98.07%	1.29%	-0.45	Accept
97.06%	1.67%	97.48%	1.10%	0.79	Accept
97.80%	1.45%	98.13%	1.06%	0.72	Accept
98.02%	1.27%	98.25%	1.06%	0.54	Accept
97.95%	1.36%	98.04%	1.27%	0.19	Accept
99.09%	0.88%	98.78%	1.01%	-0.63	Accept
98.86%	0.98%	98.78%	0.88%	-0.22	Accept
99.11%	0.71%	99.22%	0.83%	0.43	Accept
99.50%	0.38%	99.54%	0.35%	0.30	Accept
99.68%	0.34%	99.56%	0.41%	-0.84	Accept
99.85%	0.17%	99.84%	0.20%	-0.11	Accept

Continuous Review					
Full Run		Independent Run		Test of	
Percent	Std Dev	Percent	Std Dev	z-Score	Differences
97.68%	1.42%	96.79%	1.60%	-1.45	Accept
98.76%	1.05%	97.92%	1.33%	-1.89	Accept
98.04%	1.30%	98.00%	1.40%	-0.09	Accept
97.87%	1.20%	97.78%	1.37%	-0.24	Accept
97.95%	1.36%	97.40%	1.51%	-1.84	Accept
97.61%	1.48%	97.14%	1.50%	-0.84	Accept
98.25%	1.05%	97.85%	1.28%	-0.94	Accept
98.03%	1.36%	97.55%	1.27%	-1.80	Accept
97.36%	1.33%	96.96%	1.52%	-0.65	Accept
98.02%	1.36%	97.63%	1.40%	-0.74	Accept
97.54%	1.29%	97.03%	1.35%	-1.85	Accept
97.91%	1.36%	97.48%	1.47%	-0.82	Accept
97.40%	1.35%	96.61%	1.60%	-1.65	Accept
97.02%	1.62%	96.92%	1.27%	-0.19	Accept
98.04%	1.25%	97.56%	1.45%	-0.99	Accept
97.81%	1.03%	97.42%	1.16%	-0.95	Accept
98.25%	0.90%	98.27%	0.87%	0.03	Accept
98.80%	0.74%	98.92%	0.58%	0.12	Accept
99.64%	0.31%	99.56%	0.31%	-0.68	Accept
99.99%	0.03%	99.99%	0.03%	-0.14	Accept

Instantaneous Reorder					
Full Run		Independent Run		Test of	
Percent	Std Dev	Percent	Std Dev	z-Score	Differences
97.96%	1.27%	97.96%	1.17%	0.00	Accept
97.31%	1.32%	97.52%	1.32%	0.45	Accept
97.14%	1.39%	97.69%	1.44%	-0.99	Accept
96.40%	1.62%	96.42%	1.43%	-0.11	Accept
99.06%	0.65%	99.12%	0.61%	0.51	Accept
98.78%	1.21%	98.87%	0.72%	0.23	Accept
98.40%	0.95%	98.53%	0.85%	0.39	Accept
98.09%	1.14%	98.06%	0.94%	-0.03	Accept
97.49%	1.40%	97.64%	1.15%	0.29	Accept
99.06%	0.85%	98.93%	0.74%	-0.60	Accept
98.66%	0.83%	98.29%	1.00%	-1.10	Accept
97.40%	1.38%	97.22%	1.32%	-0.55	Accept
98.53%	1.10%	98.56%	0.87%	0.09	Accept
97.26%	1.17%	97.27%	1.17%	0.17	Accept
98.02%	0.95%	97.85%	1.07%	-0.46	Accept
97.75%	1.23%	97.90%	1.05%	0.38	Accept
98.52%	0.70%	98.55%	0.76%	0.11	Accept
98.04%	0.90%	97.80%	0.90%	-0.71	Accept
98.57%	0.73%	98.47%	0.76%	-0.36	Accept
98.77%	0.81%	98.46%	0.72%	-1.28	Accept

95 Percent Service Level

Periodic Review						Continuous Review						Instantaneous Reorder					
Full Run		Independent Run		Test of		Full Run		Independent Run		Test of		Full Run		Independent Run		Test of	
Percent	Std Dev	Percent	Std Dev	z-Score	Differences	Percent	Std Dev	Percent	Std Dev	z-Score	Differences	Percent	Std Dev	Percent	Std Dev	z-Score	Differences
92.57%	2.96%	92.14%	2.74%	-0.41	Accept	97.66%	1.44%	96.79%	1.69%	-1.52	Accept	97.93%	1.29%	97.90%	1.20%	-0.08	Accept
91.90%	2.79%	91.54%	2.50%	-0.37	Accept	97.27%	1.73%	96.45%	1.87%	-1.24	Accept	97.35%	1.36%	97.44%	1.35%	0.18	Accept
96.04%	2.42%	95.86%	2.20%	-0.21	Accept	95.79%	2.36%	96.14%	1.82%	0.46	Accept	97.11%	1.30%	97.06%	1.44%	-0.10	Accept
95.30%	2.15%	94.88%	2.36%	-0.62	Accept	96.30%	1.94%	95.63%	1.93%	-0.95	Accept	96.46%	1.56%	96.34%	1.65%	-0.21	Accept
94.14%	2.34%	94.86%	1.92%	0.93	Accept	96.50%	1.42%	95.01%	2.28%	-2.34	Reject	96.01%	1.55%	95.80%	1.76%	-0.21	Accept
93.20%	2.60%	93.70%	2.12%	0.58	Accept	96.03%	1.61%	94.61%	2.34%	-1.96	Accept	94.80%	2.16%	95.15%	2.29%	0.32	Accept
96.10%	2.59%	96.32%	1.53%	0.18	Accept	94.81%	2.08%	93.88%	2.14%	-1.23	Accept	94.19%	2.00%	94.35%	2.50%	0.19	Accept
95.75%	2.14%	95.50%	1.90%	-0.22	Accept	96.70%	1.32%	95.67%	1.40%	-2.08	Reject	98.24%	1.25%	98.06%	0.95%	-0.46	Accept
93.96%	1.95%	93.60%	2.10%	-0.24	Accept	96.24%	1.56%	95.35%	1.67%	-1.54	Accept	97.32%	1.46%	97.50%	1.18%	0.38	Accept
95.82%	1.84%	95.90%	2.00%	0.13	Accept	95.30%	1.74%	94.55%	1.81%	-1.16	Accept	96.45%	1.43%	96.43%	1.43%	-0.04	Accept
94.83%	1.85%	94.92%	1.80%	0.13	Accept	96.25%	1.84%	95.73%	1.41%	-0.87	Accept	95.55%	1.67%	94.87%	1.82%	-1.07	Accept
95.87%	2.02%	96.00%	1.57%	0.21	Accept	95.01%	2.26%	94.56%	1.61%	-0.64	Accept	97.54%	1.37%	97.22%	1.32%	-0.64	Accept
96.27%	1.90%	96.73%	1.60%	0.72	Accept	95.78%	1.48%	95.37%	1.52%	-0.76	Accept	95.58%	1.74%	95.82%	1.75%	0.38	Accept
96.48%	1.40%	96.54%	1.70%	0.10	Accept	95.62%	1.85%	95.55%	1.63%	-0.12	Accept	97.11%	1.16%	97.26%	1.17%	0.35	Accept
96.53%	1.63%	96.25%	1.64%	-0.47	Accept	95.74%	1.50%	95.11%	1.48%	-1.12	Accept	94.38%	1.73%	94.43%	1.70%	0.08	Accept
96.76%	1.27%	96.78%	1.58%	0.03	Accept	94.57%	2.04%	94.62%	1.77%	0.07	Accept	94.65%	1.97%	94.91%	1.72%	0.38	Accept
98.32%	0.96%	98.19%	1.30%	-0.31	Accept	96.40%	2.15%	96.58%	1.20%	0.29	Accept	96.62%	1.17%	96.56%	1.18%	-0.13	Accept
98.53%	0.81%	98.47%	0.84%	-0.20	Accept	97.55%	0.94%	97.31%	1.03%	-0.57	Accept	95.38%	1.24%	95.64%	1.38%	-0.51	Accept
98.68%	0.65%	98.64%	0.76%	-0.15	Accept	98.63%	0.78%	98.35%	0.76%	-1.06	Accept	97.31%	0.93%	97.16%	1.06%	-0.42	Accept
99.21%	0.45%	99.16%	0.53%	-0.24	Accept	99.91%	0.13%	99.85%	0.18%	-1.03	Accept	96.60%	0.96%	96.32%	1.15%	-0.95	Accept

92 Percent Service Level

Periodic Review						Continuous Review						Instantaneous Reorder					
Full Run		Independent Run		Test of		Full Run		Independent Run		Test of		Full Run		Independent Run		Test of	
Percent	Std Dev	Percent	Std Dev	z-Score	Differences	Percent	Std Dev	Percent	Std Dev	z-Score	Differences	Percent	Std Dev	Percent	Std Dev	z-Score	Differences
92.40%	2.91%	91.67%	3.09%	-0.66	Accept	94.80%	2.43%	93.71%	2.62%	-1.29	Accept	97.79%	1.44%	97.77%	1.22%	-0.04	Accept
91.65%	2.53%	90.98%	2.65%	-0.71	Accept	94.81%	2.10%	93.43%	2.68%	-1.58	Accept	97.39%	1.42%	97.26%	1.47%	-0.25	Accept
90.46%	3.05%	89.76%	3.92%	-0.57	Accept	93.74%	2.43%	92.94%	2.65%	-0.87	Accept	97.09%	1.26%	96.92%	1.56%	-0.33	Accept
89.17%	3.01%	87.66%	3.40%	-1.28	Accept	93.43%	2.56%	92.30%	2.55%	-1.21	Accept	96.48%	1.65%	96.18%	1.70%	-0.49	Accept
94.13%	2.36%	94.20%	2.03%	0.20	Accept	96.57%	1.43%	95.01%	2.28%	-2.30	Reject	95.93%	1.68%	95.62%	1.97%	-0.46	Accept
93.28%	2.61%	93.42%	2.24%	0.15	Accept	96.03%	1.61%	94.61%	2.34%	-1.96	Accept	94.83%	2.14%	94.93%	2.37%	0.11	Accept
91.79%	3.42%	91.40%	2.40%	-0.37	Accept	94.79%	1.99%	93.88%	2.14%	-1.21	Accept	94.17%	2.06%	94.23%	2.51%	0.07	Accept
90.50%	3.08%	90.23%	2.70%	-0.25	Accept	94.33%	1.85%	93.01%	2.05%	-1.85	Accept	93.05%	2.57%	93.04%	2.98%	-0.01	Accept
93.87%	2.32%	93.55%	2.23%	-0.38	Accept	93.85%	2.26%	92.10%	2.15%	-2.18	Reject	97.44%	1.48%	97.34%	1.38%	-0.20	Accept
91.98%	2.37%	91.71%	2.67%	-0.20	Accept	95.30%	1.74%	94.04%	1.80%	-1.96	Accept	96.45%	1.43%	96.34%	1.49%	-0.20	Accept
94.73%	1.88%	94.78%	2.05%	0.08	Accept	94.28%	1.80%	93.28%	1.87%	-1.48	Accept	95.59%	1.61%	94.76%	1.90%	-1.19	Accept
92.14%	2.28%	92.33%	2.23%	0.24	Accept	93.06%	2.41%	92.13%	1.76%	-1.21	Accept	92.79%	2.31%	92.63%	2.44%	-0.18	Accept
93.29%	2.40%	93.70%	2.27%	0.53	Accept	93.76%	2.19%	93.31%	1.65%	-0.65	Accept	95.71%	1.61%	95.78%	1.79%	0.12	Accept
94.50%	2.11%	94.20%	2.08%	-0.51	Accept	94.04%	1.88%	93.70%	1.71%	-0.52	Accept	92.58%	2.14%	92.76%	2.20%	0.23	Accept
96.44%	1.60%	96.18%	1.65%	-0.43	Accept	93.91%	1.41%	93.40%	1.64%	-0.75	Accept	94.58%	1.62%	94.30%	1.81%	-0.17	Accept
94.83%	1.69%	94.82%	2.12%	-0.01	Accept	93.65%	1.88%	92.77%	2.01%	-1.24	Accept	94.83%	1.90%	94.87%	1.73%	0.07	Accept
95.80%	1.59%	96.05%	2.01%	0.38	Accept	93.56%	2.10%	93.27%	1.55%	-0.34	Accept	92.91%	1.78%	92.92%	1.90%	0.01	Accept
96.91%	1.43%	96.95%	1.37%	0.08	Accept	95.51%	1.50%	95.35%	1.40%	-0.30	Accept	95.88%	1.22%	95.63%	1.38%	-0.34	Accept
97.05%	1.02%	97.07%	1.17%	0.07	Accept	97.52%	0.92%	97.24%	0.99%	-0.79	Accept	95.32%	1.32%	94.99%	1.33%	-0.68	Accept
97.98%	0.99%	98.09%	0.82%	0.33	Accept	99.53%	0.42%	99.54%	0.35%	0.06	Accept	95.00%	1.21%	94.48%	1.46%	-1.08	Accept

85 Percent Service Level

Periodic Review					
Full Run		Independent Run		Test of	
Percent	Std Dev	Percent	Std Dev	z-Score	Differences
81.56%	3.51%	77.34%	4.74%	-2.90	Reject
90.85%	2.80%	88.03%	4.56%	-2.07	Reject
90.79%	2.28%	85.87%	5.77%	-3.36	Reject
89.20%	2.60%	83.83%	4.59%	-4.09	Reject
87.44%	3.34%	82.22%	4.32%	-3.73	Reject
85.22%	3.63%	80.11%	5.40%	-3.09	Reject
91.67%	3.32%	86.11%	4.59%	-3.85	Reject
90.32%	3.19%	87.72%	3.15%	-2.24	Reject
88.64%	2.52%	84.33%	3.71%	-3.79	Reject
91.76%	2.26%	89.85%	3.29%	-1.89	Accept
89.93%	2.76%	89.02%	3.36%	-0.82	Accept
92.10%	2.31%	91.27%	2.77%	-0.89	Accept
88.67%	2.51%	87.93%	3.26%	-0.70	Accept
90.66%	3.01%	89.20%	3.00%	-1.25	Accept
89.91%	2.62%	89.30%	2.80%	-0.62	Accept
92.49%	2.54%	91.64%	2.80%	-0.87	Accept
90.95%	2.25%	91.32%	2.87%	0.39	Accept
91.81%	2.06%	91.85%	2.30%	0.05	Accept
94.79%	1.89%	94.11%	1.71%	-1.04	Accept
94.35%	1.39%	94.83%	1.44%	0.92	Accept

Continuous Review					
Full Run		Independent Run		Test of	
Percent	Std Dev	Percent	Std Dev	z-Score	Differences
88.68%	3.09%	0.883981	0.032804	-0.24	Accept
88.58%	2.78%	0.879035	0.033579	-0.80	Accept
87.40%	3.27%	0.873562	0.032461	-0.03	Accept
87.90%	2.41%	0.866449	0.031718	-1.23	Accept
87.33%	3.02%	0.856845	0.032779	-1.43	Accept
91.93%	3.05%	0.912036	0.029142	-0.67	Accept
92.14%	2.27%	0.903267	0.028391	-1.95	Accept
91.00%	2.36%	0.892092	0.02908	-1.86	Accept
89.61%	2.05%	0.879664	0.030624	-1.50	Accept
88.04%	2.70%	0.862621	0.031355	-1.67	Accept
90.19%	2.18%	0.895571	0.027809	-0.71	Accept
89.52%	3.05%	0.879473	0.029799	-1.43	Accept
86.98%	3.03%	0.856373	0.030149	-1.21	Accept
88.81%	2.46%	0.872842	0.021714	-1.81	Accept
87.90%	3.25%	0.88109	0.019586	0.31	Accept
88.33%	2.83%	0.873641	0.026499	-0.97	Accept
89.34%	2.10%	0.883599	0.019942	-1.31	Accept
91.16%	2.43%	0.898794	0.021437	-1.54	Accept
93.26%	1.88%	0.931455	0.017942	-0.17	Accept
98.44%	0.86%	0.981125	0.008178	-1.07	Accept

Instantaneous Reorder					
Full Run		Independent Run		Test of	
Percent	Std Dev	Percent	Std Dev	z-Score	Differences
90.80%	3.01%	91.11%	3.42%	0.26	Accept
90.29%	3.43%	89.88%	3.77%	-0.31	Accept
88.99%	2.49%	88.70%	3.65%	-0.26	Accept
87.65%	3.19%	87.19%	3.78%	-0.36	Accept
85.77%	3.60%	85.40%	3.93%	-0.20	Accept
94.56%	2.27%	94.61%	2.77%	-0.60	Accept
93.94%	1.94%	93.07%	3.09%	-0.94	Accept
92.89%	2.58%	92.07%	3.38%	-0.75	Accept
91.80%	2.95%	90.14%	3.72%	-1.36	Accept
89.08%	3.12%	87.90%	3.64%	-0.95	Accept
95.33%	1.72%	94.08%	2.20%	-1.70	Accept
92.85%	2.19%	91.92%	2.86%	-1.01	Accept
89.29%	3.14%	88.59%	3.28%	-0.59	Accept
92.87%	2.13%	92.33%	2.48%	-0.64	Accept
88.00%	2.82%	87.19%	2.92%	-0.78	Accept
88.55%	3.15%	88.53%	2.59%	-0.02	Accept
92.96%	1.87%	92.60%	2.08%	-0.37	Accept
92.17%	1.74%	91.58%	1.97%	-0.86	Accept
91.71%	1.77%	91.47%	1.57%	-0.38	Accept
92.35%	1.65%	92.04%	1.67%	-0.50	Accept

VITA

Major Stephan P. Brady received a Bachelor of Arts degree in Political Science from Western Maryland College in May of 1985, A Master of Science in Business Administration and Logistics from the Air Force Institute of Technology (AFIT) in September, 1992, and a Master of Public Administration degree from The University of New Hampshire in May, 1994.

Major Brady was commissioned into the United States Air Force on 24 May 1985. Upon entering active duty in the Air Force, Steve was selected as one of a few second lieutenants to enter the Logistics Plans career field. He was assigned to the historic 509th Bombardment Wing at Pease AFB, New Hampshire, holding numerous positions, ultimately serving as the Officer-in-Charge, Logistics Plans Division. Steve was then assigned to Grand Forks AFB, North Dakota, as the Chief, Logistics Plans Division. There he deployed the B-1B and KC-135R in their first conventional, bare-base deployment and was instrumental in basing the KC-135R at Cairo-West, Egypt, during DESERT SHIELD. These efforts led to his selection as Eighth Air Force Outstanding Logistics Manager for 1990.

Following his tour at AFIT, Major Brady was assigned to the Plans and Requirements Directorate, Air Mobility Command, Scott AFB, IL, as the Command Reliability and Maintainability (R&M) Manager. His efforts included R&M management of the C-17 Cargo Aircraft, the 60K "Tunner" Loader program, and various small projects. He later returned to Logistics, moving to the Air Mobility Command Logistics Directorate as the Chief, Deployment Policy. In that position he was responsible for Command policy governing worldwide deployment of forces, as well as the development and deployment of automated information systems for managing deployment of forces around the globe. He was subsequently selected to join the faculty at AFIT, and has been attending The Pennsylvania State University in preparation for that duty.

Major Brady was awarded the Air Force Achievement Medal, the Air Force Commendation Medal with oakleaf cluster, and the Air Force Meritorious Service Medal. He has also received the Humanitarian Service Medal and the National Defense Service Medal.

Major Brady is a member of the Sigma Iota Epsilon and Pi Gamma Mu Honor Societies. He is also a lifetime member of SOLE – The International Society of Logistics. Stephan is a Certified Professional Logistician.

Major Brady is from Gaithersburg, MD. His wife, Jennifer, is from Laurel, MD. They have two daughters, Stephanie and Heather, and a son, Matthew.